Earth and Mars Hypsometry

February 17, 2020

1 Hypsometry of Earth and Mars

Note: For the interested or advanced user: The ETOPO5 data can be downloaded at: ETOPO5 and information about the data can be obtained here. Note that there is a new, high resolution dataset available globally. But these data, however, are too large to perform fast calculations on them. Once you have downloaded the data, you can view them with ENVI or ArcMAP. I have used ENVI, to import the data with the following parameters (saved in the header file): Samples: 4320, Lines: 2160, Data Type: Integer, Byte Order: Network (IEEE). You can save the file as a Tif/Geotiff and import it into Matlab using either the command importdata('ETOPO5.TIF') or the using the menu File->Import data...]

Alternatively, you can download a geotiff version of the ETOPO5-geotiff.

Obtain information about the DEM file with gdal. On the command line, you can use:

```
gdalinfo DEM_geotiff/alwdgg.tif | more
```

and you will obtain:

```
Driver: GTiff/GeoTIFF
Files: DEM_geotiff/alwdgg.tif
       DEM_geotiff/alwdgg.aux
       DEM_geotiff/alwdgg.tif.rrd
Size is 4320, 2160
Coordinate System is:
GEOGCS["Clarke_1866",
    DATUM["Clarke_1866",
        SPHEROID["Clarke 1866",6378206.4,294.9786982138982]],
    PRIMEM["Greenwich",0],
    UNIT["degree",0.0174532925199433]]
Origin = (-179.999994914978743,90.000002544373274)
Pixel Size = (0.083333335816860,-0.083333335816860)
Metadata:
  AREA_OR_POINT=Area
  TIFFTAG_RESOLUTIONUNIT=1 (unitless)
  TIFFTAG_SOFTWARE=IMAGINE TIFF Support
Copyright 1991 - 1999 by ERDAS, Inc. All Rights Reserved
@(#)$RCSfile: etif.c $ $Revision: 1.9.1.2 $ $Date: 2001/12/05 00:33:12Z $
  TIFFTAG_XRESOLUTION=1
  TIFFTAG_YRESOLUTION=1
```

```
Image Structure Metadata:
  INTERLEAVE=BAND
Corner Coordinates:
Upper Left  (-179.9999949,  90.0000025) (179d59'59.98"W, 90d 0' 0.01"N)
Lower Left  (-179.9999949, -90.0000028) (179d59'59.98"W, 90d 0' 0.01"S)
Upper Right ( 180.0000158,  90.0000025) (180d 0' 0.06"E, 90d 0' 0.01"N)
Lower Right ( 180.0000158, -90.0000028) (180d 0' 0.06"E, 90d 0' 0.01"S)
Center      (   0.0000104,  -0.0000001) (  0d 0' 0.04"E,  0d 0' 0.00"S)
Band 1 Block=4320x1 Type=Int16, ColorInterp=Gray
  Description = alwdgg
  Min=-10376.000 Max=7833.000
  Minimum=-10376.000, Maximum=7833.000, Mean=-1895.840, StdDev=2658.686
  Overviews: 1078x538, 538x268, 268x133, 133x65, 65x31
  Metadata:
    LAYER_TYPE=athematic
    STATISTICS_MAXIMUM=7833
    STATISTICS_MEAN=-1895.8397216797
    STATISTICS_MINIMUM=-10376
    STATISTICS_STDDEV=2658.6857910156
```

We note that no nodata value has been assign. We also see the projection information and pixel size. Next, Load data into Python and display. Here we use richDEM and rd.LoadGDAL, but we could have used gdal and the Python API directly.

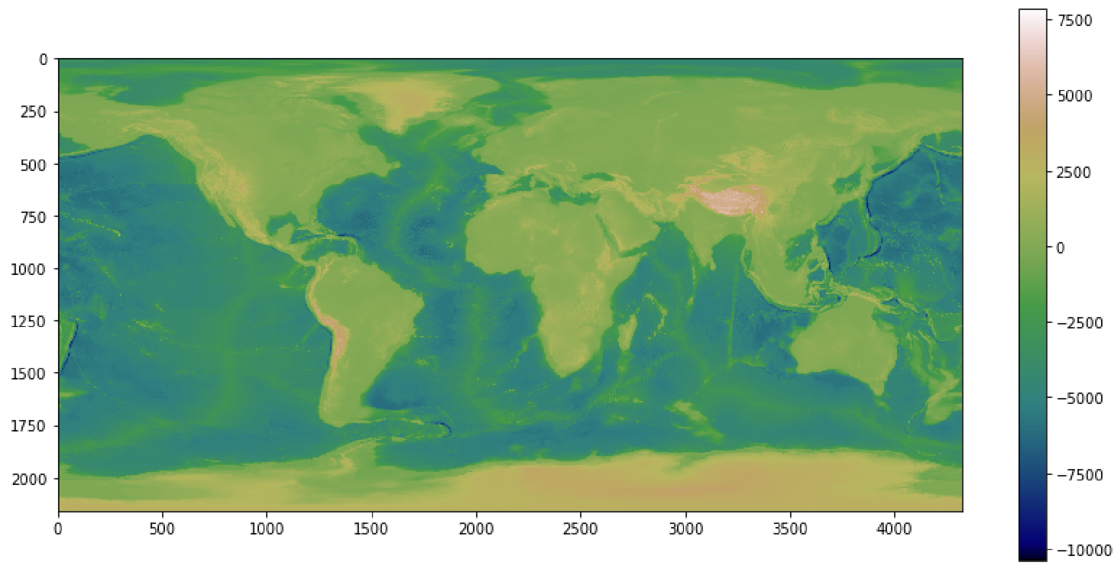
[5]:
```python
#import richdem as rd
#earth_dem = rd.LoadGDAL(earth_dem_fname, no_data=-32678)
#richdem not running on Windows systems, use gdal instead
#conda install gdal

import numpy as np
from matplotlib import pyplot as pl
pl.rcParams['figure.figsize'] = [14, 7]

from osgeo import gdal
earth_dem_fname='/home/bodo/Dropbox/Teaching/IITGn-QuantGeomorph_2020/github/
↪Earth/DEM_geotiff/alwdgg.tif'

ds = gdal.Open(earth_dem_fname, gdal.GA_ReadOnly)
rb = ds.GetRasterBand(1)
earth_dem = rb.ReadAsArray()

pl.imshow(earth_dem, interpolation='none', cmap='gist_earth')
pl.colorbar()
pl.show()
```



Question: Plot a profile across the equator

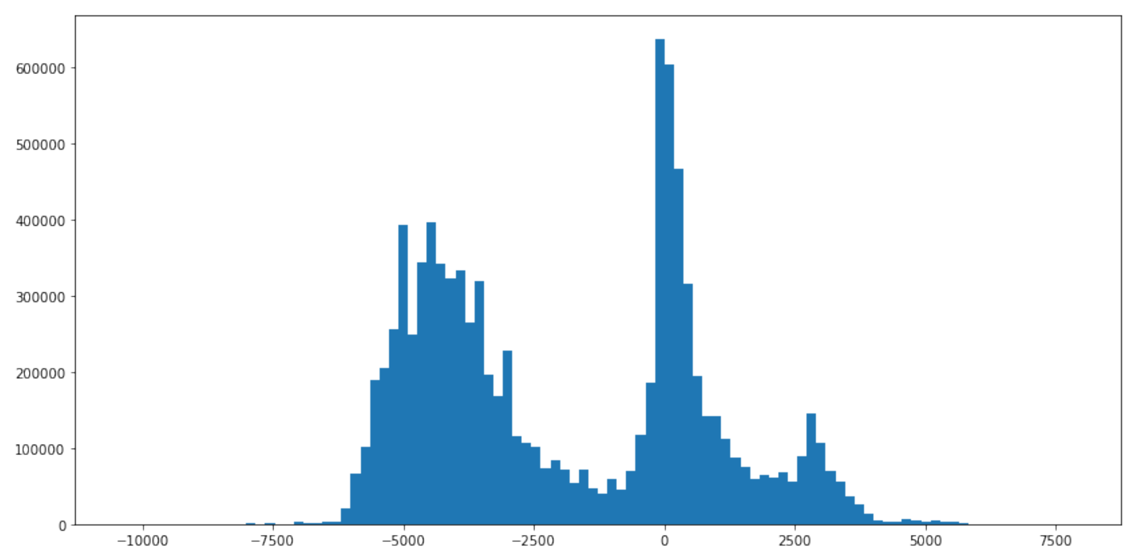
We can obtain a histogram (hypsometry) of Earth using np.hist or directly with matplotlib.pyplot.hist.

A simple histogram using 100 equally-spaced bins (hypsometry of Earth):

[7]:
```
pl.hist(earth_dem.ravel(), bins=100)
```

[7]:
```
(array([3.00000e+00, 5.00000e+00, 1.50000e+01, 2.00000e+00, 6.00000e+00,
        4.20000e+01, 4.20000e+01, 2.26000e+02, 2.00000e+02, 1.03000e+02,
        1.87000e+02, 1.40000e+02, 3.03000e+02, 9.53000e+02, 2.55000e+02,
        5.75000e+02, 4.93000e+02, 4.53000e+02, 3.16100e+03, 1.07700e+03,
        1.30300e+03, 2.87500e+03, 2.71300e+03, 2.14850e+04, 6.68590e+04,
        1.01532e+05, 1.89160e+05, 2.05411e+05, 2.55997e+05, 3.92635e+05,
        2.49754e+05, 3.43994e+05, 3.96398e+05, 3.42630e+05, 3.23799e+05,
        3.33791e+05, 2.64363e+05, 3.20423e+05, 1.96603e+05, 1.68757e+05,
        2.28883e+05, 1.16071e+05, 1.06691e+05, 1.01195e+05, 7.28270e+04,
        8.43160e+04, 7.14010e+04, 5.36310e+04, 7.23910e+04, 4.79100e+04,
        3.96860e+04, 6.01070e+04, 4.47890e+04, 6.95240e+04, 1.16677e+05,
        1.85904e+05, 6.37050e+05, 6.04667e+05, 4.67142e+05, 3.16942e+05,
        1.94659e+05, 1.42417e+05, 1.42865e+05, 1.12067e+05, 8.67240e+04,
        7.52730e+04, 5.88670e+04, 6.54750e+04, 6.17870e+04, 6.77340e+04,
        5.53450e+04, 8.91890e+04, 1.45858e+05, 1.07678e+05, 6.98980e+04,
        5.66750e+04, 3.68140e+04, 2.57010e+04, 1.30100e+04, 4.58900e+03,
        3.48100e+03, 2.90200e+03, 5.87900e+03, 4.65200e+03, 3.13000e+03,
        5.08500e+03, 2.45800e+03, 3.09700e+03, 9.09000e+02, 2.06000e+02,
        1.82000e+02, 2.50000e+01, 3.20000e+01, 7.00000e+00, 0.00000e+00,
        1.00000e+00, 0.00000e+00, 1.00000e+00, 0.00000e+00, 1.00000e+00]),
```

```
rdarray([-1.037600e+04, -1.019391e+04, -1.001182e+04, -9.829730e+03,
        -9.647640e+03, -9.465550e+03, -9.283460e+03, -9.101370e+03,
        -8.919280e+03, -8.737190e+03, -8.555100e+03, -8.373010e+03,
        -8.190920e+03, -8.008830e+03, -7.826740e+03, -7.644650e+03,
        -7.462560e+03, -7.280470e+03, -7.098380e+03, -6.916290e+03,
        -6.734200e+03, -6.552110e+03, -6.370020e+03, -6.187930e+03,
        -6.005840e+03, -5.823750e+03, -5.641660e+03, -5.459570e+03,
        -5.277480e+03, -5.095390e+03, -4.913300e+03, -4.731210e+03,
        -4.549120e+03, -4.367030e+03, -4.184940e+03, -4.002850e+03,
        -3.820760e+03, -3.638670e+03, -3.456580e+03, -3.274490e+03,
        -3.092400e+03, -2.910310e+03, -2.728220e+03, -2.546130e+03,
        -2.364040e+03, -2.181950e+03, -1.999860e+03, -1.817770e+03,
        -1.635680e+03, -1.453590e+03, -1.271500e+03, -1.089410e+03,
        -9.073200e+02, -7.252300e+02, -5.431400e+02, -3.610500e+02,
        -1.789600e+02,  3.130000e+00,  1.852200e+02,  3.673100e+02,
         5.494000e+02,  7.314900e+02,  9.135800e+02,  1.095670e+03,
         1.277760e+03,  1.459850e+03,  1.641940e+03,  1.824030e+03,
         2.006120e+03,  2.188210e+03,  2.370300e+03,  2.552390e+03,
         2.734480e+03,  2.916570e+03,  3.098660e+03,  3.280750e+03,
         3.462840e+03,  3.644930e+03,  3.827020e+03,  4.009110e+03,
         4.191200e+03,  4.373290e+03,  4.555380e+03,  4.737470e+03,
         4.919560e+03,  5.101650e+03,  5.283740e+03,  5.465830e+03,
         5.647920e+03,  5.830010e+03,  6.012100e+03,  6.194190e+03,
         6.376280e+03,  6.558370e+03,  6.740460e+03,  6.922550e+03,
         7.104640e+03,  7.286730e+03,  7.468820e+03,  7.650910e+03,
         7.833000e+03]),
<a list of 100 Patch objects>)
```



Question: Change the binning parameters to obtain bins spaced in 250-m elevation

slices

Question: We have used a geographic projection system. This is distorted at the higher latitude. It will be more useful to have an equal-area projection such as Mollweide. Either use 'gdal' to convert the projection or load the data contained in `ETOPO5_dem_mollweide_geotiff.zip`. Make sure to properly assign the nodata value and repeat the binning analysis (results with not be very different, but more accurate.

[ ]:
```
bins_250m = np.linspace(-10000,10000, 250)
```

2 Hypsometry of Mars

Next, we load a DEM of Mars. There is a high resolution MARS MOLA DEM available (1000 m spatial resolution) that I prepared. But this is of high resolution and the analysis performed on this file may take a little longer. Instead, we will rely on a 5000m DEM of Mars `mola128_mola64_merge_90Nto90S_SimpleC_clon0_5000m_bilinear.tif`. But feel free to experiment with other resolution data. Again, we first obtain information about the geotiff file:

`gdalinfo mola128_mola64_merge_90Nto90S_SimpleC_clon0_5000m_bilinear.tif`

with the following output:

```
Driver: GTiff/GeoTIFF
Files: mola128_mola64_merge_90Nto90S_SimpleC_clon0_5000m_bilinear.tif
Size is 4268, 2134
Coordinate System is:
PROJCS["Mars2000_ECylindrical_clon0",
    GEOGCS["GCS_Mars_2000_Sphere",
        DATUM["Mars_2000_Sphere",
            SPHEROID["Mars_2000_Sphere",3396190,0]],
        PRIMEM["Reference_Meridian",0],
        UNIT["degree",0.0174532925199433]],
    PROJECTION["Equirectangular"],
    PARAMETER["latitude_of_origin",0],
    PARAMETER["central_meridian",0],
    PARAMETER["standard_parallel_1",0],
    PARAMETER["false_easting",0],
    PARAMETER["false_northing",0],
    UNIT["metre",1,
        AUTHORITY["EPSG","9001"]]]
Origin = (-10669677.095995118841529,5334954.318897561170161)
Pixel Size = (5000.000000000000000,-5000.000000000000000)
Metadata:
  AREA_OR_POINT=Area
  DataType=Generic
Image Structure Metadata:
  COMPRESSION=DEFLATE
  INTERLEAVE=BAND
```

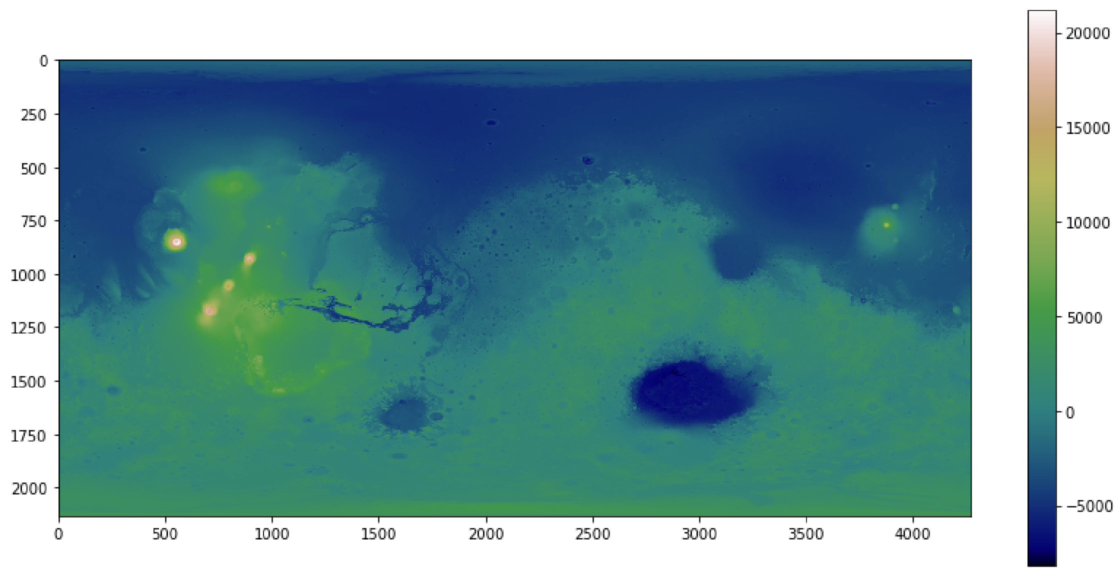
```
Corner Coordinates:
Upper Left  (-10669677.096, 5334954.319) (179d59'45.94"E, 90d 0'14.06"N)
Lower Left  (-10669677.096,-5335045.681) (179d59'45.94"E, 90d 0'19.61"S)
Upper Right (10670322.904, 5334954.319) (179d59' 6.71"W, 90d 0'14.06"N)
Lower Right (10670322.904,-5335045.681) (179d59' 6.71"W, 90d 0'19.61"S)
Center      (     322.904,     -45.681) (  0d 0'19.61"E,  0d 0' 2.77"S)
Band 1 Block=4268x1 Type=Int16, ColorInterp=Gray
  NoData Value=-32768
```

[ ]:

[6]:

```
mars_dem_fname='/home/bodo/Dropbox/Teaching/IITGn-QuantGeomorph_2020/github/
↪Earth/mola128_mola64_merge_90Nto90S_SimpleC_clon0_5000m_bilinear.tif'
#mars_dem = rd.LoadGDAL(mars_dem_fname, no_data=-32768)

ds = gdal.Open(mars_dem_fname, gdal.GA_ReadOnly)
rb = ds.GetRasterBand(1)
mars_dem = rb.ReadAsArray()
pl.imshow(mars_dem, interpolation='none', cmap='gist_earth')
pl.colorbar()
pl.show()
```



Question: What geomorphic/tectonic features do you observe on Mars?

Question: Calculate the hypsometry of Mars and make one plot that combines Earth's and Mars' Hypsometries. Why are they different?

Question: Compare the slope distribution of Mars and Moon. How and why are these different?

You can either use the numerical slope function we have created before or you use the Terrainattributes function included in richDEM. For example:

```
slope = rd.TerrainAttribute(mars_dem, attrib='slope_riserun')
rd.rdShow(slope, axes=False, cmap='magma', figsize=(8, 5.5))
plt.show()
```

Question: A lot of information is contained in 2D histogram. You can evaluate slope and elevation (i.e., what slope dominates at what elevation) using a 2D kernel density estimator. See here.

Question: The directory contains a DEM of Moon - load this and calculated hypsometry as well