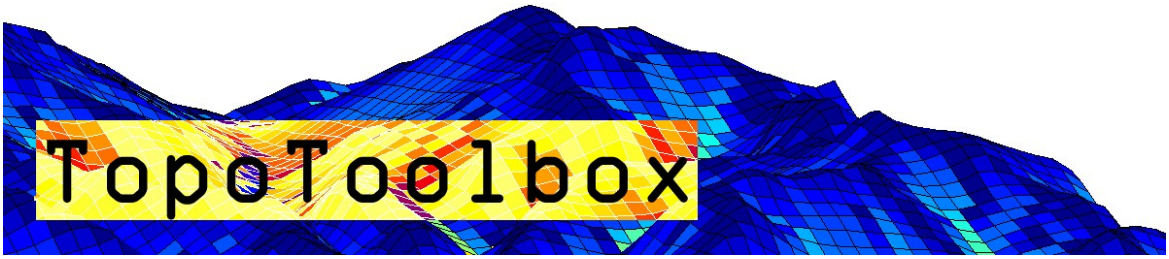
User Guide to TopoToolbox - Introduction



TopoToolbox provides a set of Matlab functions that support the analysis of relief and flow pathways in digital elevation models. The major aim of TopoToolbox is to offer helpful analytical GIS utilities in a non-GIS environment in order to support the simultaneous application of GIS-specific and other quantitative methods.

TopoToolbox is written in the Matlab language and requires the Image Processing Toolbox. In addition, the Mapping Toolbox is recommended to have as it enables working with different cartographic projections and simplifies data exchange (reading of geotiffs, reading and writing of shapefiles).

TopoToolbox 2

TopoToolbox version 2 is a major update to the Toolbox. The main difference to previous versions are

- the introduction of an Object Oriented Programming (OOP) approach and the implementation of new classes such as GRIDobj, FLOWobj and STREAMobj. All objects carry information (properties) on spatial referencing, information that was previously stored using coordinate matrices that required large memory space.
- a new representation of flow direction. TopoToolbox 1 used the sparse flow direction matrix to store flow direction and compute flow related variables. The new representation allows for much faster function evaluation that usually requires much less overhead memory.
- various GUIs mainly for geomorphological and geomorphometric applications which are intended to make various analyses easier and faster.
- higher computational efficiency by coding various functions as C-MEX files. Note that these functions should be compiled on your system. However, TopoToolbox runs without compilation, yet, less fast.

About the User Guide

This user guide is intended as a basic introduction to the TopoToolbox. It won't give a comprehensive overview on the functions available but serves a documentation for a simple session. In addition, this user guide provides an account for the command-line based tools of TopoToolbox only. It does not expand upon the use of the GUIs.

Load a DEM into Matlab

TopoToolbox 2 reads the ESRI ascii grid format and single band geotiffs into an instance of GRIDobj.

Note that, throughout the use of TopoToolbox, it is assumed that the DEM has a projected coordinate system (e.g. UTM WGS84) and that elevation and horizontal coordinates are in meter units.

```
DEM = GRIDobj('srtm_bigtujunga30m_utm11.tif');
```

DEM is now an instance of the class `GRIDobj`. DEM contains various properties that contain the gridded data and information on the spatial referencing of the grid.

```
DEM
```

```
DEM = 
  GRIDobj with properties:

          Z: [643×1197 single]
   cellsize: 30
     refmat: [3×2 double]
       size: [643 1197]
       name: 'srtm_bigtujunga30m_utm11'
      zunit: []
     xyunit: []
     georef: [1×1 struct]
```

The data is stored in the property `.Z`. You can access it using linear indexing, subscripts or logical indexing as you are used to do with standard MATLAB matrices and arrays. E.g. the upper-left 5x5 pixel in the grid can be accessed by following command.

```
DEM.Z(1:5,1:5)
```

```
ans = 
5×5 single matrix
  945  952  960  966  969
  944  951  956  959  957
  936  943  948  949  948
  929  935  939  941  940
  921  926  929  934  930
```

GRIDobj is associated with various methods. Some of these methods overwrite existing builtin functions (e.g. `plus`, `minus`, `isnan`). Here is an overview of the methods (functions) that can be called with an instance of GRIDobj.

```
methods GRIDobj
```

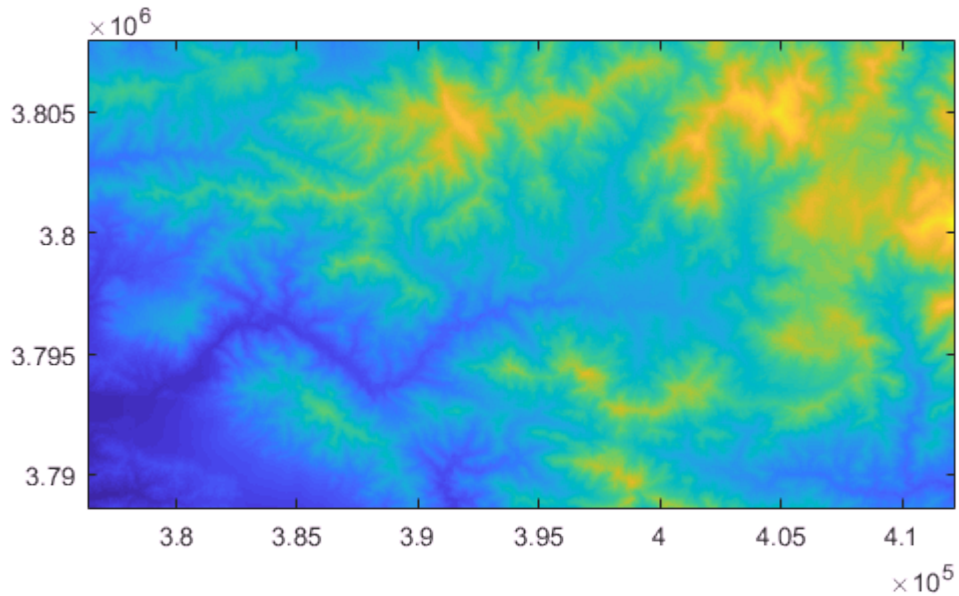
```
Methods for class GRIDobj:

GRIDobj            createmask         ge                 interp             mpower             shufflelabel
GRIDobj2ascii      crop               getcoordinates     interp2GRIDobj     mrdivide           snap2stream
GRIDobj2geotiff    curvature          getoutline         isnan              mtimes             sqrt
GRIDobj2mat        demarea            gradient8          ldivide            not                sub2coord
GRIDobj2pm         demprofile         griddedcontour     le                 or                 surf
GRIDobj2polygon    dilate             gt                 line2GRIDobj       pad                times
acv                distance           hillshade          localtopography    plus               toposhielding
all                elevateminima      hillshademdow      log                polygon2GRIDobj    uminus
and                eq                 hypscurve          log10              postprocflats      uplus
any                erode              identifyflats      log2               power              validatealignment
arcslope           excesstopography   identifyridges     lt                 rdivide            xor
```

```
aspect          fahrboeschung   imagesc         max             reclassify      zonalstats
castshadow      fillsinks       imageschs       measure         reproject2utm   zscore
contour         filter          ind2coord       min             resample
coord2ind       find            info            minmaxnorm      ridges
coord2sub       findcoord       inpaintnans     minus           roughness
```

View the DEM

Matlab provides numerous ways to display gridded data (images). Among these are `imagesc`, `surf`, `pcolor`, `imshow`, etc. TopoToolbox overwrites only `imagesc` and `surf`

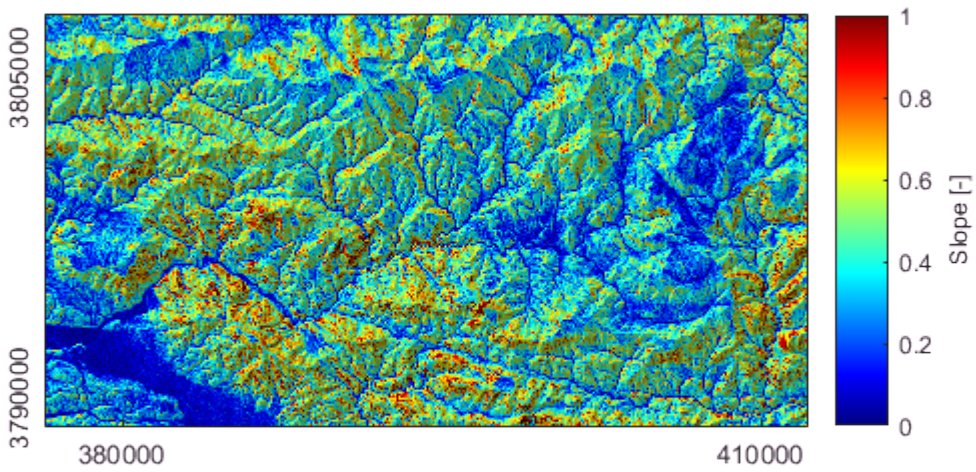
```
imagesc(DEM)
```



Note that the axes contain the x and y coordinates and that the axes are scaled equally.

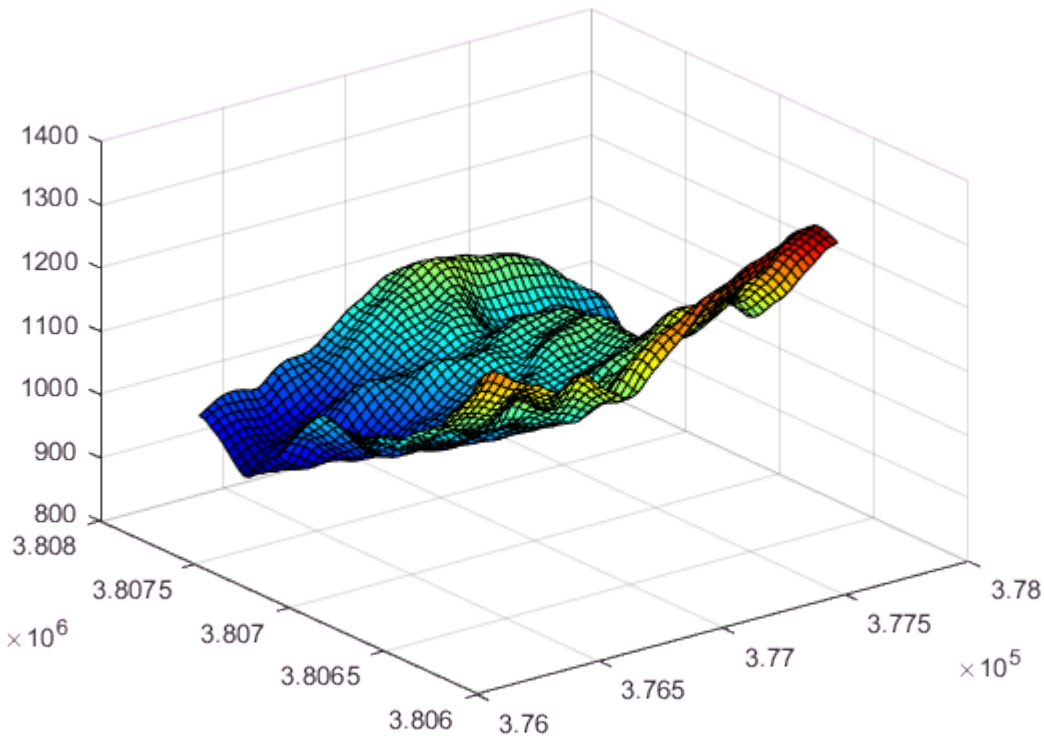
Another useful function is imageschs which displays an instance of `GRIDobj` and overlays it with the DEM. Here we display the slope (see function `gradient8`) overlayn with the hillshade calculated from DEM. For visualization purposes the color range is restricted to slopes less than 1 m/m.

```
G = gradient8(DEM);
imageschs(DEM,G,'ticklabel','nice','colorbarylabel','Slope [-]','caxis',[0 1])
```



If none of the available visualization functions are what you are looking for, you can simply convert your DEM to the standard representation using GRIDobj2mat. The function returns two coordinate vectors and a matrix with values. Here we crop our DEM to a smaller extent before plotting.

```
DEMc = crop(DEM,sub2ind(DEM.size,[1 50],[1 50]));
[Z,x,y] = GRIDobj2mat(DEMc);
surf(x,y,double(Z))
```



Note: See the help of the function `crop` on other ways to clip your data to a desired extent.

Topographic attributes

Topographic attributes are derivatives obtained from a DEM such as slope, exposition or curvature. We assume that you are familiar with the meaning of these attributes and you will notice must of the functions by their function name such as

- `gradient8` -> as opposed to the Matlab builtin gradient function, `gradient8` calculates the gradient in 8 possible directions for each cell and takes the maximum.
- `curvature` -> the second derivative of a DEM.
- `roughness` -> allows you calculate various roughness indices related to intercell, topographic variability such as ruggedness etc.
- `aspect` -> slope exposition
- and many more

Export an instance of GRIDobj to the disk

TopoToolbox ships with two functions for writing instances of GRIDobj back the hard drive so that they can be read by standard GIS software such as ArcGIS etc.

```
GRIDobj2ascii(DEMc,'test.txt');
GRIDobj2geotiff(DEMc,'test.tif');
```

Note that writing geotiffs is possible without having the mapping toolbox available. However, TopoToolbox will then write an image with a tfw-file (worldfile) which will be used by other GIS software to georeference the grid. Yet, the grid won't have a projection which must then be defined in GIS. See help `GRIDobj2geotiff` for details.

Fill sinks

Often DEMs feature erroneous topographic depressions that should be filled prior to flow path computation. You can fill sinks using the function `fillsinks`. Note that in some situations it is more appropriate to not fill sinks but to carve the DEM which will be shown below (see section on FLOWobj).

```
DEMf = fillsinks(DEM);
```

FLOWobj and flow related functions

Users of previous versions of TopoToolbox will remember that flow directions were stored as a sparse matrix that contained the information of the directed acyclic graph of the flow network. TopoToolbox 2 uses a novel technique to store flow direction that allows for easy coding and fast performance. Flow direction is stored as a new object, `FLOWobj`, an instance of which is derived from an existing DEM (instance of `GRIDobj`).

Here is a fast way to calculate flow accumulation based on the previously sink filled DEM. The flow accumulation grid is dilated a little bit, so that flow paths are more easily appreciated in the figure.

```
FD = FLOWobj(DEMf);
A  = flowacc(FD);
imageschs(DEM,dilate(sqrt(A),ones(5)),'colormap',flipud(copper),...
    'colorbarylabel','Flow accumulation [sqrt(# of pixels)]',...
    'ticklabel','nice');
```

When creating an instance of `FLOWobj`, you can set numerous options that are summarized in the help of `FLOWobj`.

Methods associated with FLOWobj

Various methods exist that operate on instances of FLOWobj to obtain flow related variables such as drainage basin delineation, flow accumulation, etc. Here is an overview

```
methods FLOWobj
```

```
Methods for class FLOWobj:

FLOWobj              coord2ind            find                 imposemin            saveobj              validatea
FLOWobj2GRIDobj      dbentropy            flowacc              ind2coord            streamorder          vertdista
FLOWobj2M            dependencemap        flowconvergence      influencemap         streampoi
FLOWobj2cell         drainagebasins       flowdistance         ismulti              updatetoposort
FLOWobj2gradient     drainagebasinstats   flowpathextract      multi2single         upslopestats
```

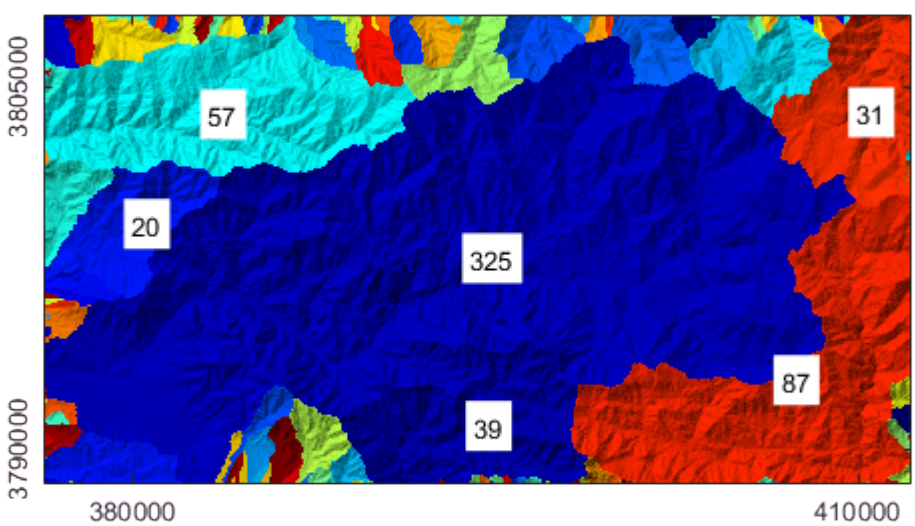
Now, let's calculate the drainage basins of the DEM. This can be done using the function `drainagebasins`. You may want to shuffle the colors so that the drainage basins can be more easily distinguished in a plot (`shufflelabel`). As a small exercise, let's denote the area of each basin in the map.

```
DB = drainagebasins(FD);
```

```
DB = shufflelabel(DB);
```

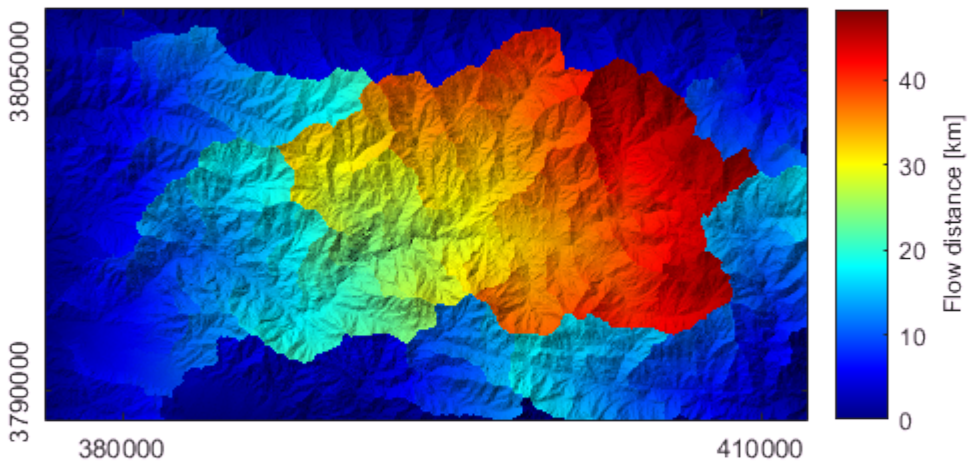
Easy until here. Now let's get the area and display it together with the drainage basins map. To avoid overlapping labels, let's display only numbers for drainage basins larger than 10 km^2.

```
nrDB = numel(unique(DB.Z(:)))-1; % nr of drainage basins
STATS = regionprops(DB.Z,'PixelIdxList','Area','Centroid');

imageschs(DEM,DB,'colorbar',false,'ticklabel','nice');

hold on
for run = 1:nrDB;
    if STATS(run).Area*DB.cellsize^2 > 10e6;
        [x,y] = ind2coord(DB,...
            sub2ind(DB.size,...
            round(STATS(run).Centroid(2)),...
            round(STATS(run).Centroid(1))));
        text(x,y,...
            num2str(round(STATS(run).Area * DB.cellsize^2/1e6)),...
            'BackgroundColor',[1 1 1]);
    end
end
hold off
```



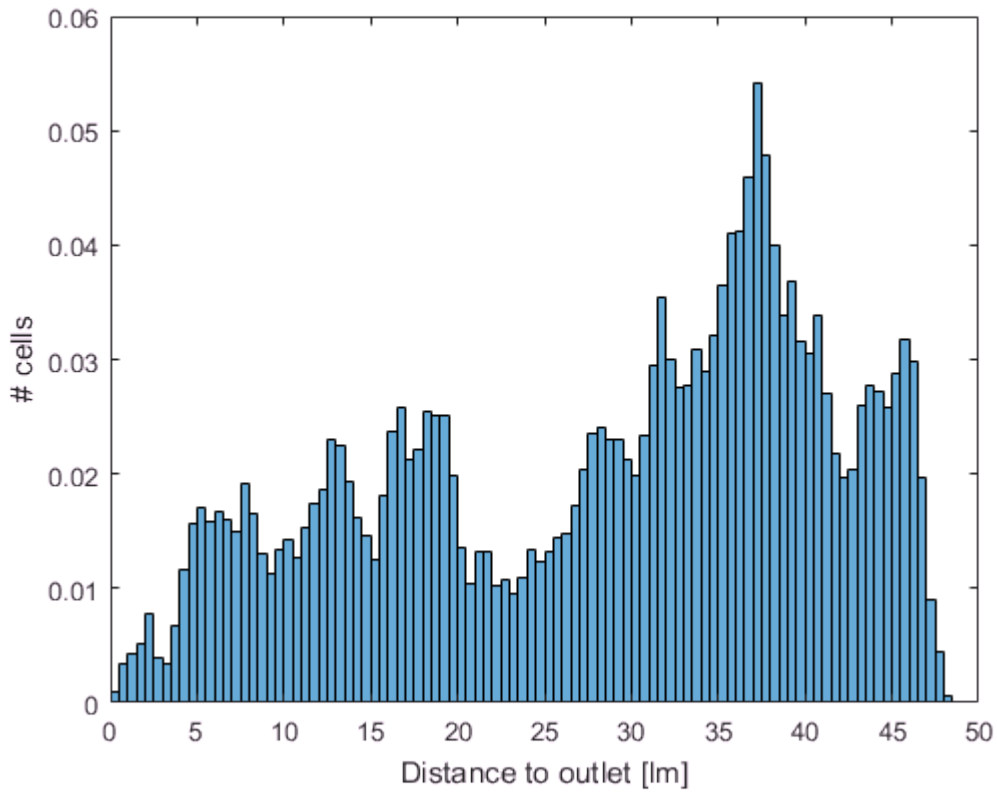
It may also be interesting to know the distance from each drainage basin outlet in upstream direction along the flow network.

```
D = flowdistance(FD);
D = D/1000;
imageschs(DEM,D,'ticklabel','nice','colorbarylabel','Flow distance [km]')
```



You can use the output of flowdistance to calculate the area function which is the frequency distribution of flow distances to the outlet of a specific basin. Let's take the largest basin in our study site.

```
[~,IX] = max([STATS.Area]);
histogram(D.Z(DB.Z == IX),'Normalization','pdf');
xlabel('Distance to outlet [lm]');
ylabel('# cells');
```



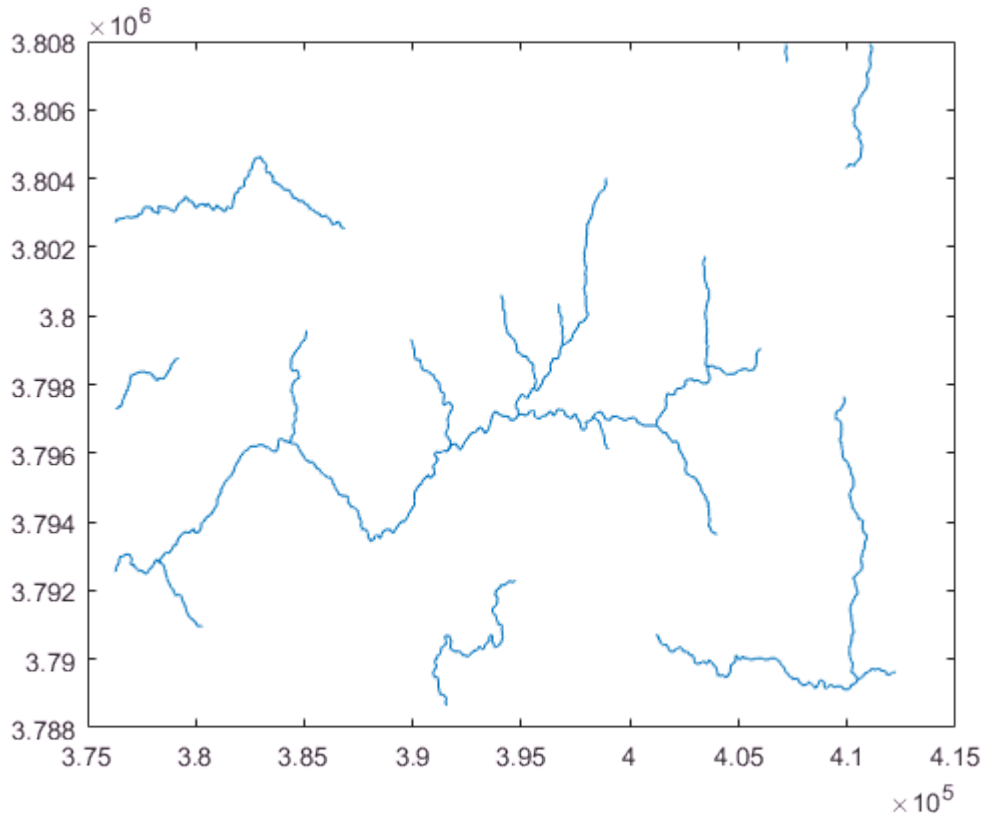
STREAMobj - a class for stream networks

While FLOWobj stores the information on the entire flow network on hillslopes and in channels, STREAMobj is a class that is used to analyze the channelized part of the flow network only. The storage strategy is very similar to the one of the class FLOWobj.

Again, various methods (functions) are associated with STREAMobj that allow for manipulating, plotting and retrieving information on the stream network geometry and patterns.

There are various ways to extract the channelized flow network from DEMs. In this example we simply use an area threshold.

```
% calculate flow accumulation
A = flowacc(FD);
% Note that flowacc returns the number of cells draining
% in a cell. Here we choose a minimum drainage area of 10000 cells.
W = A>10000;
% create an instance of STREAMobj
S = STREAMobj(FD,W);
% and plot it
plot(S);
```




```
axis image
```

STREAMobj stores various properties some of which you might use to directly access if you want to customize your code or build your own functions. Please check the help of STREAMobj.

Like the other TopoToolbox objects, STREAMobj are associated with numerous methods that enable modifying the geometry of the stream network, to extract trunk streams, to smooth, etc. An overview is again listed by the command

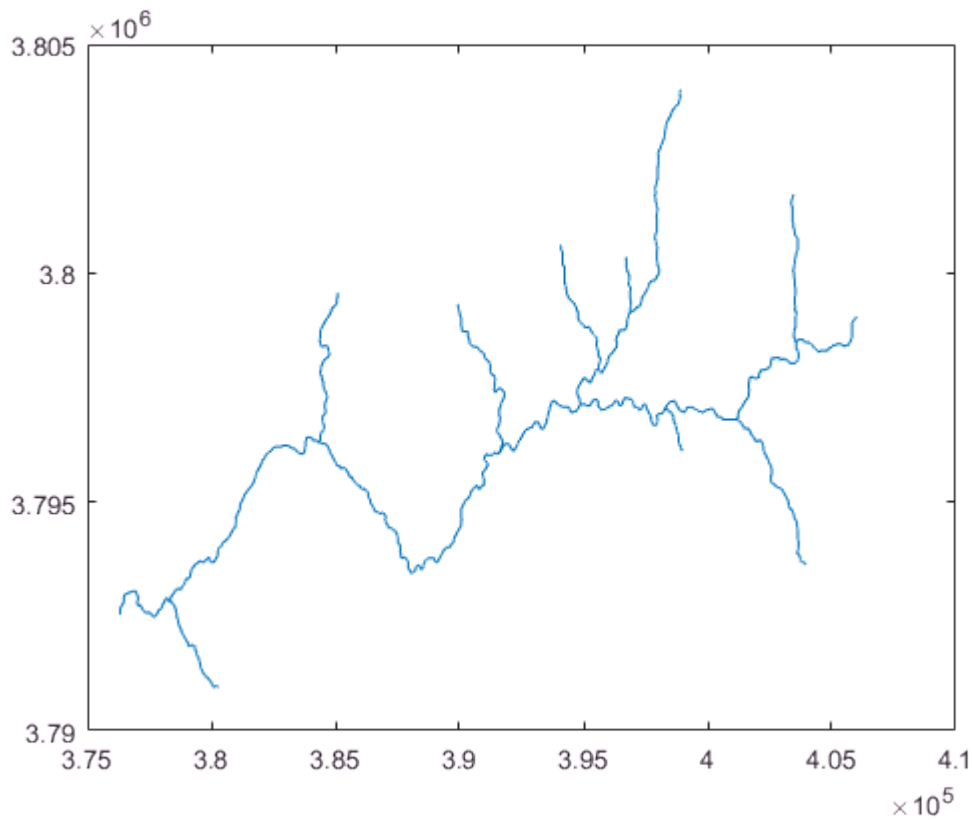
```
methods STREAMobj
```

```
Methods for class STREAMobj:

STREAMobj            getnal               plotdz
STREAMobj2GRIDobj    gradient             plotdzshaded
STREAMobj2SWATHobj   identifyflats        plotstreamorder
STREAMobj2XY         imposemin            quantcarve
STREAMobj2cell       info                 randlocs
STREAMobj2digraph    inpaintnans          removeshortstreams
STREAMobj2latlon     intersect            sidebranching
STREAMobj2mapstruct  intersectlocs        smooth
aggregate            isnal                snap2stream
chitransform         klargestconncomps    split
conncomps            ksn                  streamorder
connector            labelreach           streampoi
crs                  maplateral           streamproj
crsapp               mchi                 transformcoords
crslin               meanupstream         trunk
```

```
cummaxupstream       mincosthydrocon      union
cumtrapz             modify               validatealignment
curvature            orientation          widenstream
densify              plot                 wmplot
distance             plot3
extractbydistance    plot3d
extractconncomps     plotc
```

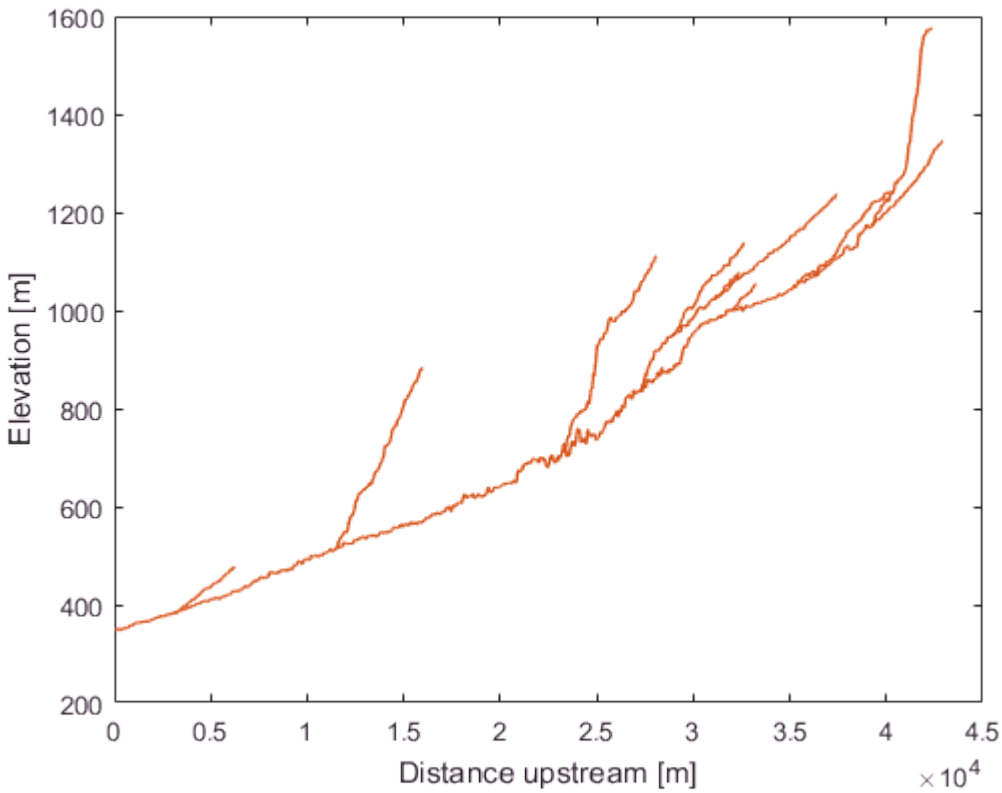
Now let's extract the largest subnetwork of the channel network.

```
S = klargestconncomps(S,1);
plot(S); axis image
```



and let's plot flow distance along the stream network versus elevation.

```
plotdz(S,DEM)
```



If you have a license of Matlab's Mapping Toolbox you can export the stream network to a shapefile to be read by other GIS software. First, you need to create a mapstruct, a structure array used by the mapping toolbox to store vector data. Then use shapewrite to write the mapstruct to a shapefile.

```
MS = STREAMobj2mapstruct(S);
shapewrite(MS,'testshape.shp')
```

Reference

Schwanghart, W., Scherler, D. (2014): TopoToolbox 2 – MATLAB-based software for topographic analysis and modeling in Earth surface sciences. Earth Surface Dynamics, 2, 1-7. [DOI: 10.5194/esurf-2-1-2014]

Schwanghart, W., Kuhn, N.J. (2010): TopoToolbox: a set of Matlab functions for topographic analysis. Environmental Modelling & Software, 25, 770-781. [DOI: 10.1016/j.envsoft.2009.12.002]

History

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