

8 Part 2: Short introduction to elementary landscape analysis with RiverTools

Acknowledgement: large thanks to Scott Peckham, programmer and owner of Rivertools (rivix.com) who has kindly agreed to freely release a set of fully functional RT licenses for the duration of this course. Please contact Scott at peckhams@rivix.com if you are interested in getting a license of Rivertools for your own research (academic discount is available).

9 Introduction and scope

To describe in a quantitative manner, analyze and understand landscapes and landscape forming processes, geomorphologists measure several aspects of the topography. Most of these measures exist since the beginning of the discipline and can be performed on classical topographic maps, but the recent satellite cartography of the Earth's surface has made available high resolution digital elevation models (DEM) which use is very powerful for the systematic analysis of landscapes. Geographic Information Systems (GIS) softwares are extremely powerful and developed tools used for mapping and understanding a large number of problems which have a spatial attribute, from physical features of the landscape, human geography indicators, social parameters etc... However, while it is possible to find landscape analysis tools for the classical most used GIS softwares (such as ArcGis), there also exists smaller more focused computer programs dedicated to landscape analysis which can be an interesting alternative for users investigating purely geomorphological problems. We will use Rivertools developed by Scott Peckham (<http://www.rivertools.com/>) because it is a user-friendly, point-and-click GIS environment developed specifically for digital terrain analysis as it relates to surface hydrology. Also, Rivertools is developed in IDL which allows for a faster treatment of large and heavy DEMs.

In this tutorial, we will first treat an example together and you will then apply these learnings to your own case study.

The present document comes as a suite of instructions that you can mark each time you complete one.

10 Get topographic data and build your DEM

10.1 Get a Digital Elevation Model

You can obtain a .kmz file for GoogleEarth at <http://www.ambiotek.com/topoview> which allows you to download large srtm tiles (shuttle radar topography mission) directly from the GE interface.

Download the 4 tiles that compose the South Island of New Zealand. Choose the geotiff format as it reads usually without problem in Rivertools.

Extract all from the .zip files.

Open Rivertools and import each of the tiff files one after another using **File/Import DEM/** This creates .rtg (rivertools grid) and .rti (rivertools info) files that allow the files to then be directly and quickly read by RT.

You can now display each of the imported DEMs using one of the various display options under **Display/** Try for instance density plot and shaded relief. You can also play with the IDL color codes (e.g. Rainbow).

10.2 Patch several DEMs together

Patch the 4 DEMs into a single one using **Prepare/Patch RTG DEMs**

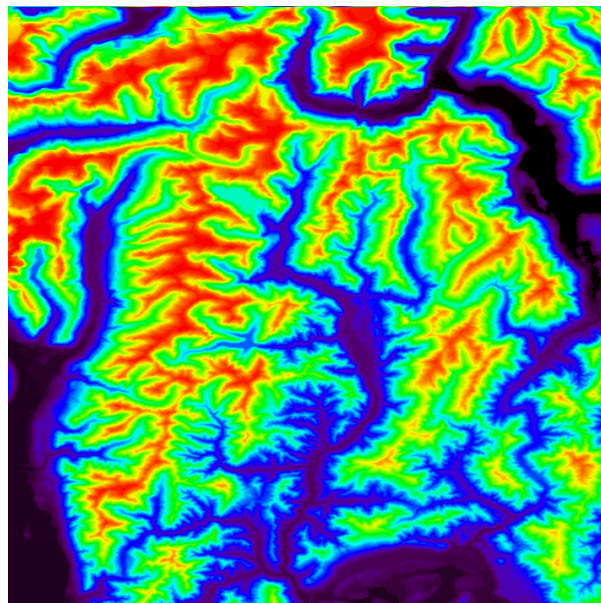
You can either select an area of interest in the window showing the newly patched DEM or save the entire DEM. In the option menu top left **save new DEM**. It will have the name that you provided in the Patch RTG DEMs window

Display this DEM with the display tool and try out the different zooming tools. **File/Open Data Set** Choose your new DEM **Display/Shaded relief**
Play with different color tables and shading parameters (white peaks) e.g. IDL color table (go to rainbow icon in the toolbar and choose Rainbow). Display scale (Tools/add scale). In the Shaded relief window: play with Tool/magnify ; Tool/value zoom ; Tool/surface zoom ; Tool/Density Zoom (e.g., figure 1), etc...

Notice that when you use the **Tool/value zoom**, you can get the x, y and elevation of the pointed pixel and the elevation of all neighbouring pixels. You will also remark that the numbers representing x and y are about 170 and -44. These are degrees of longitude and latitude that are the initial units of the geographic projection of the DEM imported from GoogleEarth. There is currently no way to change this directly in RiverTools (I use version 3.0) so if you want to work with different distance units you may want to prepare your DEM beforehand.
Alternatively, you can complete the whole analysis in RT with whatever projection that comes with the DEM you use and then reproject all what is needed in a different software afterwards. Softwares that are very handy to change projections and select given areas of DEMs are GlobalMapper or its free equivalent dlgv32 Pro available at <http://mcmcweb.er.usgs.gov/drc/dlgv32pro/>.

dlgv32 Pro and GlobalMapper are also very practical to patch DEMs.

Figure 1: A “density zoom” with the Rainbow color code



10.3 Measure topography

In the “Density plot” window, try “line profile” in order to obtain a topographic section and check that distances and elevations are sensible (sometimes, due to data format conversions, distance and elevation metrics may be altered).

Note that you in the profile window, you can go [Save Profile to File](#) in order to export the topographic section as a row-column file in .txt and process it further in any other software that you like.

11 Extract the drainage network

To study the drainage network of any DEM, one first has to extract a number of different RT_files following the order indicated in the Extract dialog.

11.1 Extract flow grid

Go: [Extract/1. Flow Grid \(D8\)](#)

The “Pit Resolution Method” dialog asks you whether you want water to flow out of lakes and continue the drainage (i.e. [fill all depressions](#)) or not ([allow closed basins](#)). In general you will choose to fill all depressions and route the water all the way from your peaks to your coasts or to the boundaries of your study area.

The “Flat resolution method” dialog asks you the method you wish to use to route water on flat areas. More details are given in the Help menu, but the fastest is [iterative linking](#). The others may give better results, i.e. less straight drainage on lakes. The choice of one or the other will depend on the case study so you may want to try them out. For the sake of our exercise, and considering the large size of our New Zealand DEM I advise you to use the [iterative linking](#).

From `/help/usr_guide/E_flow_grid` : In order to create a D8 flow grid, RiverTools first creates a depressionless DEM from your original DEM. It assumes that there are two copies of your original DEM grid file in the current directory, a “raw” version which is to be left unaltered, and another version in which the depressions are to be filled. These two RTG files typically have the filename extensions “_rawDEM.rtg” and “_DEM.rtg”.

About the D8 Method: The flow direction from each grid cell to one of its adjacent or diagonal neighbors is calculated. Slope is evaluated in the direction of steepest descent and is reported as drop/distance, i.e. \tan of the angle. Flow direction is reported as “no data” for any grid cell adjacent to the edge of the DEM domain, or adjacent to a no data value in the DEM. In flat areas flow directions are assigned away from higher ground and towards lower ground using the method of Garbrecht and Martz (1997). (Imposed gradients).

11.2 Basin Outlet

Because we first want to study the whole drainage network of the NZ DEM, we will skip this point and go directly to [Extract/3. RT Treefile](#)

At a later stage however, you may want to study individual drainage basins. In this case, the [Extract/2. Basin outlet](#) is useful.

Go: [Extract/2. Basin outlet](#)

Try it out by giving a name to one basin of interest (it could be a river name, or just something like “test_outlet” if you don’t know yet), and go “start”. You will see a shaded relief map appear. Click anywhere on the land surface: what appears is the path followed by water as it flows downstream from the point you clicked to the base level. By moving the cursor in the “Extract outlet dialog” you define a point on this path at the transition between red and white. Clicking “save outlet” will save this point as an outlet for future drainage network extraction.

Close the shaded relief window and extract outlet dialog box.

11.3 RT Treefile and River Network

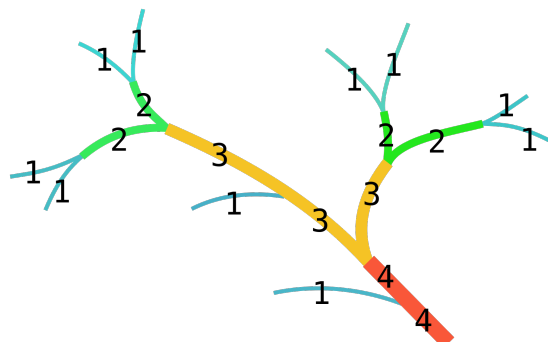
Go: [Extract/3. RT Treefile](#)

Here you can choose between extracting the treefile only above an outlet that you saved before (or among a list of many outlets saved before), or extracting the treefile of “all basins draining to edge”. We will first do “all basins draining to edge”. This may take several minutes.

When RT is “Finished with treefile extraction”, go to [Extract/4. River Network](#).

The new “Extract River Network Dialog” window that opened asks you several things. Leave the “Basin filename prefix” unchanged. In the “Source Identification Method” you can choose the way the streams will be initiated. RT will “prune” the network, like one can “prune” the fruits or branches of a tree, i.e. will remove some branches of the network according to the threshold that you will specify. One way is to assume that streams initiate after a certain amount of overland flow has gathered sufficient power to concentrate a channel. Usually, a minimum drainage area of 1km^2 is assumed to be necessary to initiate stream erosion. So, you can choose to “Prune by”: “Upstream area (km^2 , D8)”, and then use a threshold of 1km^2 . If you choose 0 as a threshold, you will simply have a drainage network extending all the way up to the landscape crests. The larger the pruning threshold the less detail in your drainage network and the faster the drainage network extraction. Here however, even with a pruning threshold of 1km^2 on the drainage area it should be relatively fast.

Figure 2: The Strahler stream ordering method



Now you can display the extracted network: [Display / River Network](#)

In the “River Network Dialog” the `_links` file corresponds to the network you just extracted, and the `_tree` file corresponds to the whole flow routing drainage network. Try them out to see the difference.

Depending on the degree of detail that you want to see displayed you can again prune the network. At this stage it is practical to prune according to the Strahler ordering scheme, see figure 2 for an illustration.

11.4 Exporting a shapefile of your river network

At this stage you may want to export a vector shapefile (`.shp`) of your network in order to have it geo-referenced in another application of your choice.

To do this, simply go **File / Export Vector / Channels**. Choose your `_links.rtv` file, the export format (`.shp` or `.txt`), and the attributes that you would like to be also exported. Note that the exported vector file is the same as the one you display with no pruning threshold. If you would like to export a lower resolution file (i.e. with less streams and less details), re-extract your drainage network with a larger pruning threshold (it will re-create a new `_links.rtv` file).

Using vector files may be done under Globalmapper, dlv32, ArcGis etc...
Tools to convert `.shp` to `.kmz` and display them into GoogleEarth are for instance available with <http://fwtools.maptools.org/> for Linux and Windows.
In matlab you may also open shapefiles with the function `shaperead`, or export the vector as `.txt` columns and open it classically.

11.5 Exporting a shapefile of the basin boundaries

To do this, you first have to extract the basin boundary. Go **Extract / Mask / Basin / Subbasin**

Then, follow the same steps as above, but choose “Boundaries” in the **File / Export Vector** path.

11.6 Exercise

Try to do all the steps necessary to obtain the drainage network and basin boundary of the “Waimakariri” river (that river with its outlet in North Christchurch).

You should be able to quickly reach something like the landscape zoom of figure 3.

12 Analyse river profiles

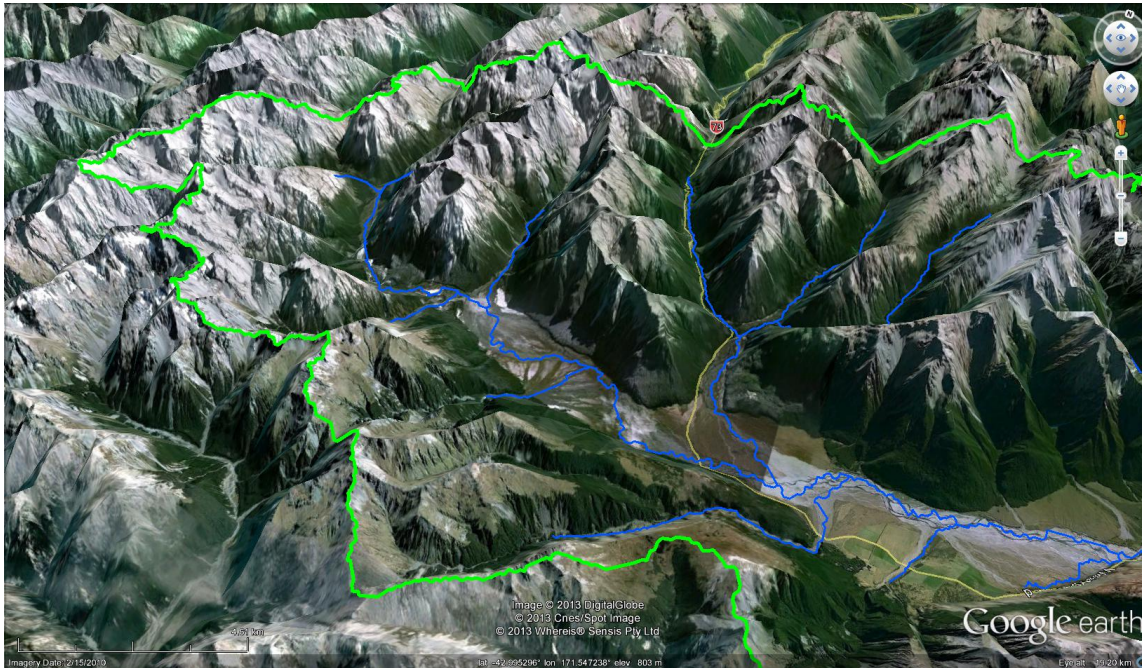
Let’s now go back to the large DEM of New Zealand: **File / Open Data Set**, choose the `_DEM.rtg` of the whole South Island.

12.1 Why rivers have a concave-up longitudinal profile?

Display a shaded relief of the South Island DEM: **Display / Shaded relief**, and, in the shaded relief window, use the **Tools / Channel Profile** to display distance-elevation plots of South Island rivers.

What do you observe?

Figure 3: 10 km² area pruned river network basin boundary of the Waimakariri river in the South Island of New Zealand. Draped over Googleearth topography.



As an example, in figure 4 one can see that the longitudinal profile of the Rangitata river is composed of two segments of very distinct shapes, an upper segment with a concave-up shape and a lower segment with a linear shape.

How can you explain these two distinct shapes?

The classical idea, as you have perhaps already seen in previous lectures or papers, is that at each point of the a fluvial landscape, erosion e is proportional to upstream drainage area A and local slope S such that:

$$e = KA^m S^n$$

with K the rock erodibility (a coefficient of proportionality), and m and n two exponents. This is the “stream power” erosion law (many variants exist).

In a “steady state” landscape submitted to an uplift U , the elevation at each point is constant with time (i.e. $dz/dt = U - e = 0$), thus one can write:

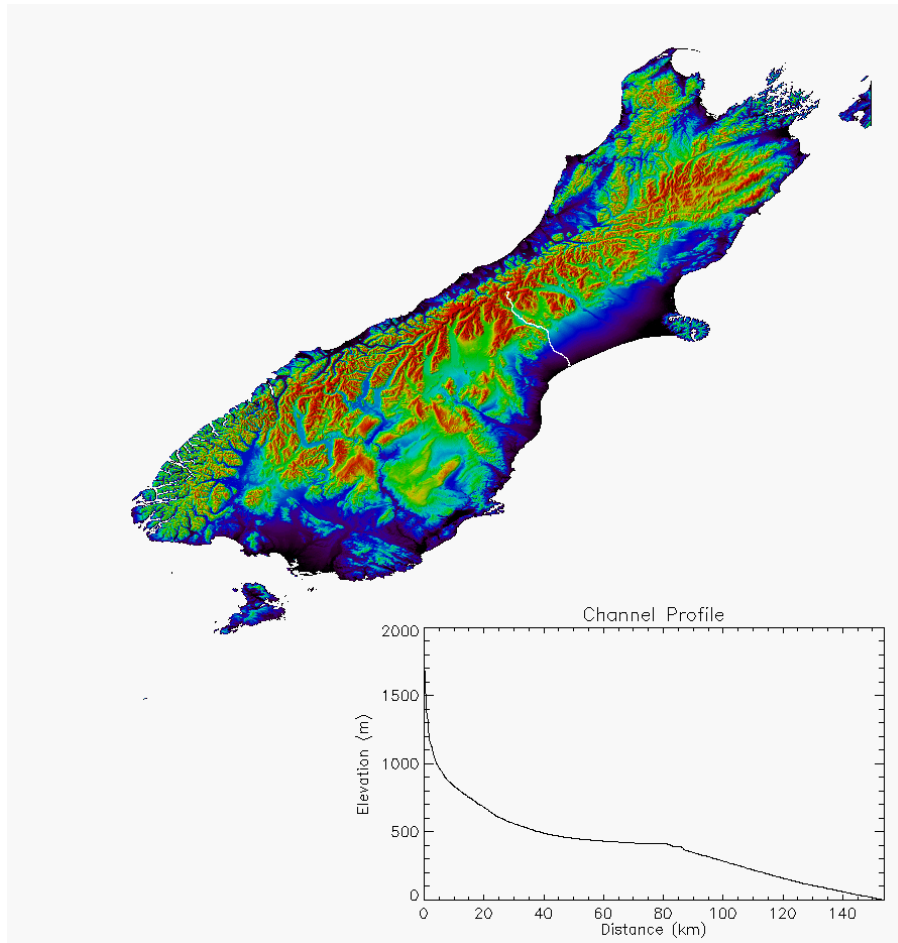
$$e = U$$

$$S = (U/K)^{1/n} A^{-m/n}$$

If one assumes for a second that $n = m = 1$, the equation above simplifies into $SA = (U/K)$, and if U and K are constant (uniform “block” uplift and uniform erodibility), one clearly sees that as A increases along a river channel by the progressive integration of an increasing number of tributaries, S decreases proportionally in order to maintain a constant erosion. This is why rivers usually become less and less steep with downstream distance.

The lower segment of the river profile is linear because drainage area does not increase anymore in the depositional plain as rivers tend to all flow relatively parallel to each others. A is constant with downstream distance, thus S is also constant.

Figure 4: Distance-elevation profile of the Rangitata river, NZ South Island



Coming back to the equations above, using river longitudinal profiles and the assumption that erosion is proportional to stream power, we can also try to find the parameters U/K and m/n . This is what we will do in the next section.

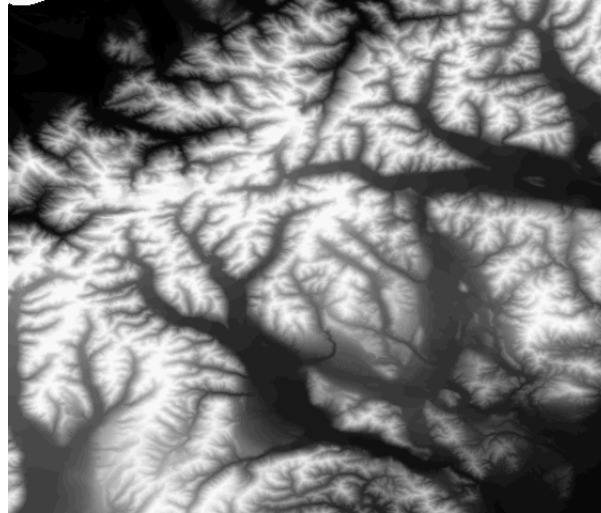
12.2 The area-slope relationship: concavity and steepness index

In this section we will study and compare the shape of the longitudinal profiles of two rivers on situated on opposite sides of the Southern Alps. To do so, we will use the relationship between area and slope along the river profiles as it tells us something about the U/K ratio.

First, with the **Prepare/Patch RTG DEMs**, choose a small subset of the whole south island DEM that encompasses the Rangitata river basin and some rivers of the western side (see figure 5). I name it `smallNZ_DEM` in the remainder.

Second, extract the flow grid (**Extract/1. Flow Grid (D8)**). Thanks to this you can now open a density plot or shaded relief of the surface and use the **Tools / Channel Profile** to obtain a longitudinal river profile of the Rangitata for instance. From such a distance elevation-profile it is easy to derive the local slope at each point (e.g. in matlab).

Figure 5: subset of the South Island New Zealand DEM, including the Rangitata river



However, to study the drainage area-slope along such a longitudinal river profile we also need to know the drainage area upstream of each point of the considered profile. To do this we extract a “drainage area grid”, i.e. a grid where drainage area is known for each cell of the studied zone.

Go **Extract / D8-based Grid / Upstream Areas**. This will produce a “smallNZ_area.rtg” file.

In the Channel Profile window of the Rangitata river, you can now go to **Options / Select Grid** and select the “smallNZ_area.rtg” file. You thus obtain, in addition to the elevation vs distance plot (lower left of figure 6), a plot of upstream contributing area versus distance (lower right of figure 6).

In the Channel Profile window, use the **Options / Save Profile to File** to save each profile under names such as Rangitata_area_distance.txt and Rangitata_elevation_distance.txt.

Use the slope_area.m code provided to plot the slope area data. You only need to enter the filenames at the beginning of the code, and to enter the distance (in kilometers) at which you identify the bedrock to alluvial transition (around 80km in the case of the Rangitata). In the lower right panel of the matlab figure produced you can now use a basic linear fitting to obtain an equation of the type:

$$\log_{10}(S) = a \log_{10}(A) + b$$

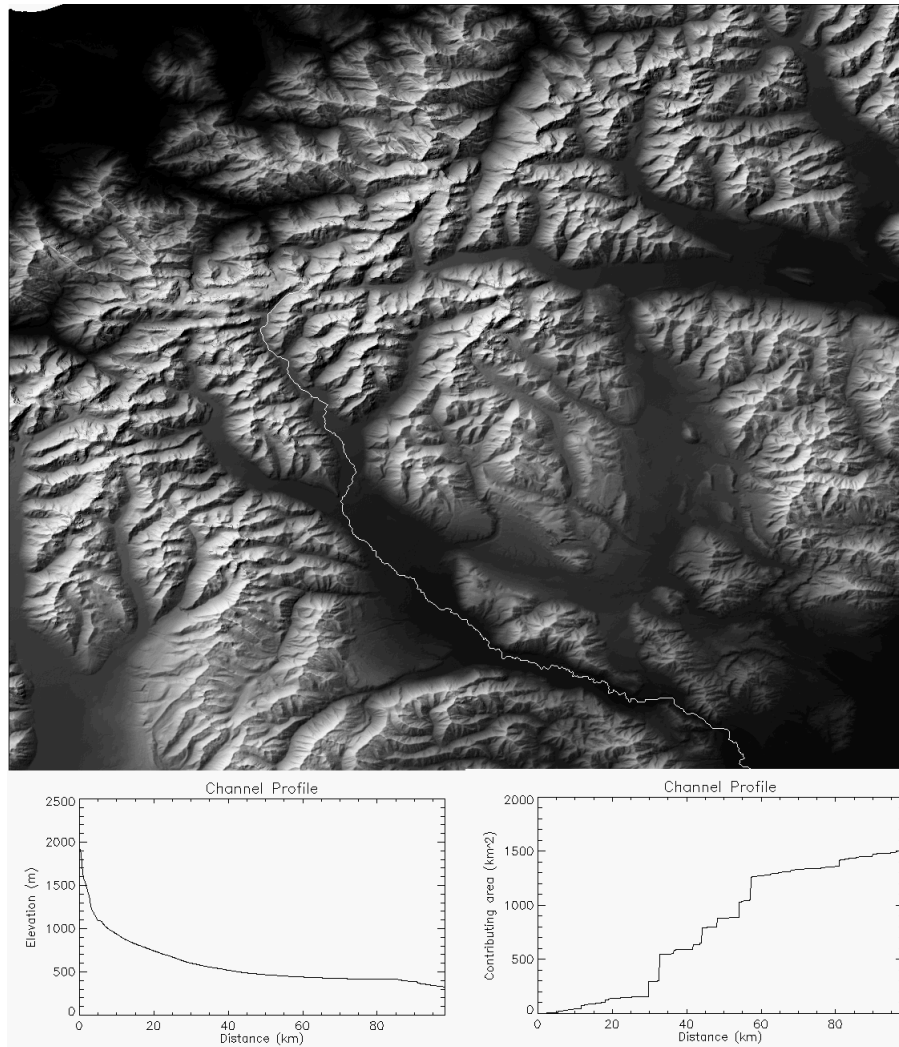
$$\text{i.e. } S = ksA^{-\theta}$$

with $ks = 10^b$ is the **steepness index** and $\theta = -a$ is the **concavity**.

```
% slope_area.m
%
% plot a "clean" slope-area relationship, useful to compute concavity and
% steepness index (streampower related parameters)
clear
clf
close all

area_filename = 'west_area_distance.txt' ;
elevation_filename = 'west_elevation_distance.txt';
area = importdata(area_filename, ' ', 6) ;
elevation = importdata(elevation_filename, ' ', 6) ;
bedrock_alluvial_transition = 25 ; %by looking at your distance_elev
% profile in Rivertools, define the bedrock-alluvial transition distance
b = max(find(area.data(:,1)<80)) ; %find the indice of the
% bedrock_alluvialtransition
a=area.data(1:b,2);
a=a*1000000.; % in m^2
```


Figure 6: Extraction of the drainage area and elevation profiles of a branch of the Rangitata river



```

x=elevation.data(1:b,1);
z=elevation.data(1:b,2);
x=x*1000.; % in meters
% initialize slope vector
s=zeros(size(x),1);
zsmooth=z;
% smooth data N times
n=5
for j=1:n
for i=2:(length(x)-1)
zsmooth(i)=(.25*zsmooth(i+1)+.25*zsmooth(i-1)+.5*zsmooth(i));
end
end
% calculate node centered slope
for i=2:(length(x)-1)
s(i)=(zsmooth(i+1)-zsmooth(i-1))/(x(i+1)-x(i-1));
if s(i)<.00001
s(i)=0.00001;
end
end
end
% plot raw area-slope data
figure(1)
subplot(2,2,1)
loglog(a(:), s(:),'ok')
xlabel('Log Area')
ylabel('Log Slope')
title('All area-slope data')
% truncate below a minimum basin size (usually 1km², i.e. 1.e6 m²)
amin=1.e6
    
```

```

nmin=2
for i=2:length(s)
    if a(i)<amin
        nmin=i;
    end
end
%take logs
loga=log10(a(nmin:end-1));
logs=log10(s(nmin:end-1));
figure(1)
subplot(2,2,2)
%log(loga,logs,'ok')
loglog(a(nmin:end-1), s(nmin:end-1),'ok')
xlabel('Log Area')
ylabel('Log Slope')
title('Truncated area-slope data')
figure(1)
subplot(2,2,3)
plot(x,z,x,zsmooth)
xlabel('Distance (m)')
ylabel('Elevation (m)')
title('River longitudinal profile')
% bin area data
nbins = 10 ; % amount of bins
abin=zeros(nbins,1);
sum=zeros(nbins,1);
num=zeros(nbins,1);
abin(1)=4.0;
for i=2:nbins
    abin(i)=abin(i-1)+0.5;
end
for ipoint=1:size(loga)
    for ibin=2:nbins
        if loga(ipoint)>abin(ibin-1) & loga(ipoint)<=abin(ibin)
            num(ibin)=num(ibin)+1;
            sum(ibin)=sum(ibin)+logs(ipoint);
        end
    end
end
sum=sum./num;
for i=1:nbins-1
    amean(i)=(abin(i+1)+abin(i))/2.;
    smean(i)=sum(i+1);
end
figure(1)
subplot(2,2,4)
plot(amean,smean,'*')
xlabel('Log Area')
ylabel('Log Slope')
title('Binned area-slope data')
    
```

In fact, as we have seen above, if we assume that the landscape is a result of the stream power of water on bedrock, and that it is at steady state (i.e. elevation remains constant everywhere), then ks tells you something about the ratio between uplift U and erodibility K , while θ tells you something about the erosion processes according to the equation see above:

$$S = (U/K)^{1/n} A^{-m/n}.$$

If one now assumes $n = 1$ then the shape of rivers can be compared in terms of U/K .

For the Rangitata river studied here you should find a $\theta \approx 0.57$ and a $ks \approx 300$.

Your question: **What can I do with that?**

Keeping in mind that the laws used here are *empirical*, I would not recommend to hope for too much robust quantitative insight from such an analysis, however, that is close to the best that is offered at the moment. For instance, you may think that it allows you to infer uplift rates, but to do that you must know the erodibility which is a ill-defined (thus also ill-calibrated) parameter.

An advice is to use the analysis in order to compare landscapes between themselves, or compare different areas of a similar landscape. For example:

- In some cases you may have an *a priori* knowledge of uplift rate from independent constraints (thermochronometry, P-T-t paths, exposure, etc...). In this case, you may use the slope-area data to look at differences in erodibility and try to link that to rock type for instance.

- In other cases, you may be able to assume that neither erosion law parameters m and n nor rock erodibility K vary regionally. In such case you try to use the slope-area data of rivers to infer lateral variations of uplift rate.

A must read if you intend to conduct such slope-area analysis is by C. Wobus, "Tectonics from topography: Procedures, promise, and pitfalls *Geological Society of America Special Papers*, **2006**, 398, p. 55-74," and the references therein.

Here we can simply look at one other river on the west side of the Southern Alps, having its source close to the source of Rangitata. Export the elevation_distance and area_distance files for it and check the bedrock to alluvial transition (around 25km).

Use the slope_area.m matlab file to derive ks and θ .

I find $\theta = 0.57$ and $ks = 794$. This may suggest that uplift U is about 2.5 higher in the west than in the east of the island.

Is this consistent with the map of figure 7?

Figure 7: Erosion rates of South Island, New Zealand, from suspended sediment yield data (from Cox et al, 2012)

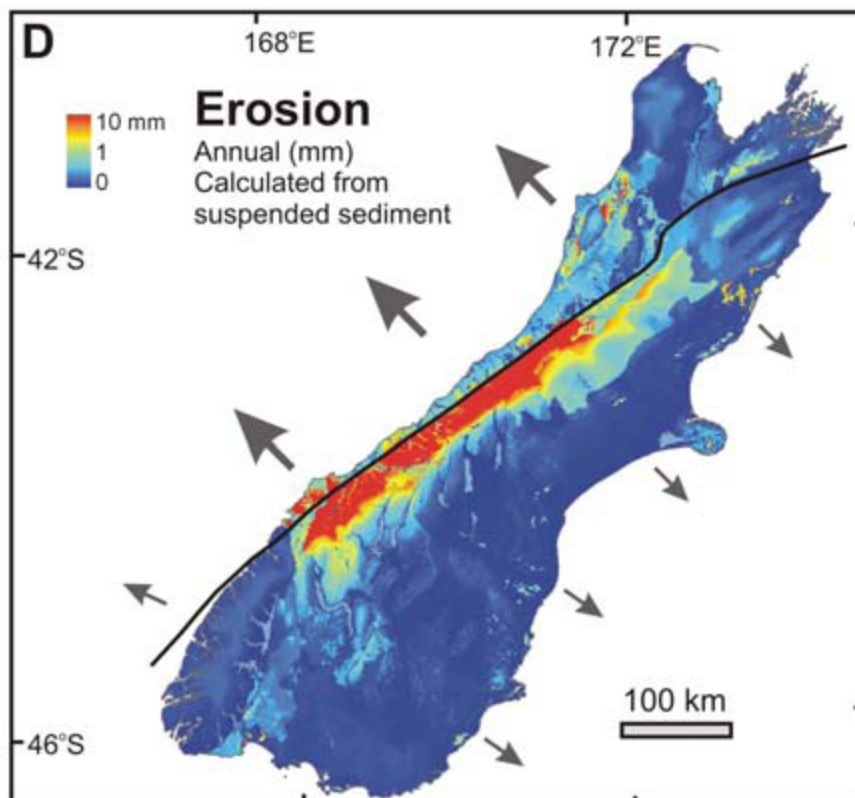
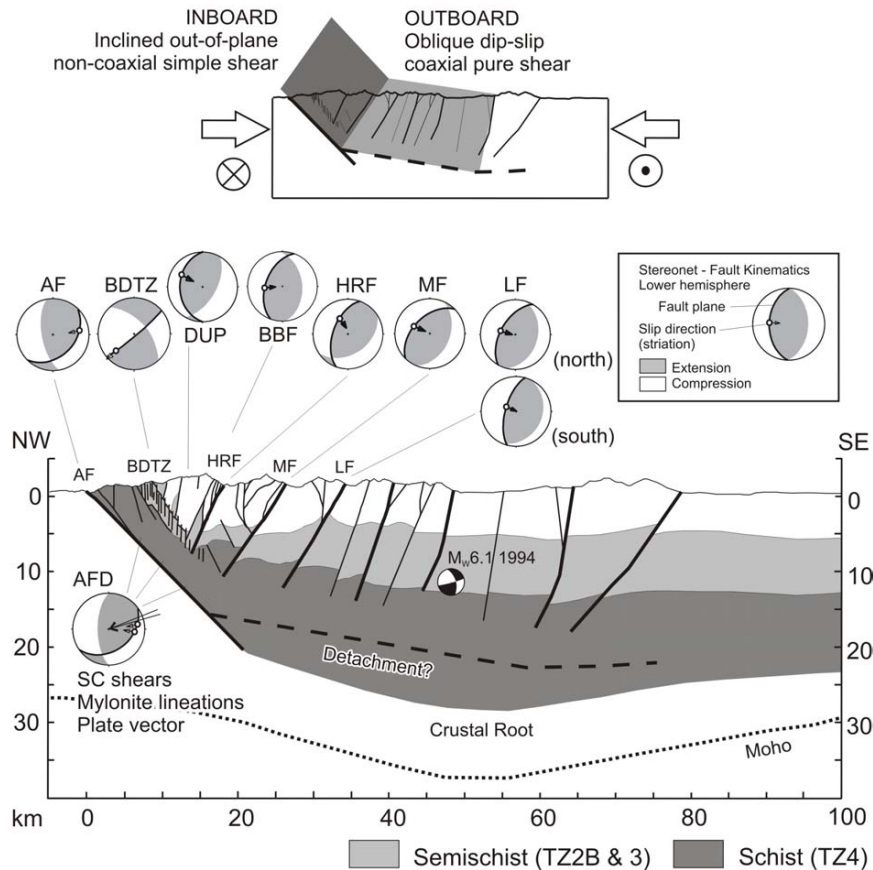


Figure 8 shows you a section across the South Island. From this section, can you figure out the expected pattern of uplift and implication for steepness indexes of rivers on the outboard and inboard of the range?

Figure 8: Section across the South Island showing location and orientation of major faults with respect to the Alpine fault, the crustal root and inferred detachment zone, New Zealand (from Cox et al, 2012 and Herman et al, 2009)



13 Advanced exercises: Analyse catchment shapes

13.1 Hack's law

- Hack's law is a log-log plot of along-channel length versus drainage area. Fit a line through your data plot of the Rangitata river (use the Hack's law plot txt file given below, - without necessarily restricting yourself to the bedrock segment of the basin). What equation do you obtain? What do the coefficient and exponent mean?
- Do the same thing using the **Extract / Data from RTV File** menu. Any difference?

```
% Hack's law plot
clear
close all
clf

area_filename = 'west_area_distance.txt' ;
area = importdata(area_filename, ' ', 6) ;
```

```
% area_filename = 'RT_data.txt' ;  
% area = importdata(area_filename, ' ', 9) ;  
  
a=area.data(2:end,2);  
a=a*1000000.; % in m^2  
  
d=area.data(2:end,1);  
d=d*1000.;  
  
loga=log10(a) ;  
logd=log10(d) ;  
figure(1)  
plot(loga,logd,'*')  
ylabel('Distance')  
xlabel('Area')
```

13.2 Extract shape and analyze orientations

Look at main rivers on the east side of the Southern Alps. How would you analyze their orientations?

In a recent paper (Castellort et al., Nature Geoscience, 2012), we analyzed river orientations and showed that rivers draining the east side of the southern alps were systematically deviated clockwise as a result of large-scale shear of the whole south island (figure 9).

Figure 9: Tectonic setting and topography of the South Island of New Zealand. a, Topography, major structures and plate tectonic setting. The Maitai Terrane (JMA, Junction Magnetic Anomaly) is offset by 480 km across the Alpine Fault and curved in the north island and southern part of south island suggesting distributed deformation over a zone wider than the Alpine Fault. b, Relief map of the Southern Alps with major river basins (black), main drainage divide (orange) and river orientation (blue). Eastern river basins 110 are transverse to the orogen close to the junction between the Hope and the Alpine Faults, and progressively rotated clockwise southwards. Western basins 1129 maintain an orogen-perpendicular orientation from north to south.

