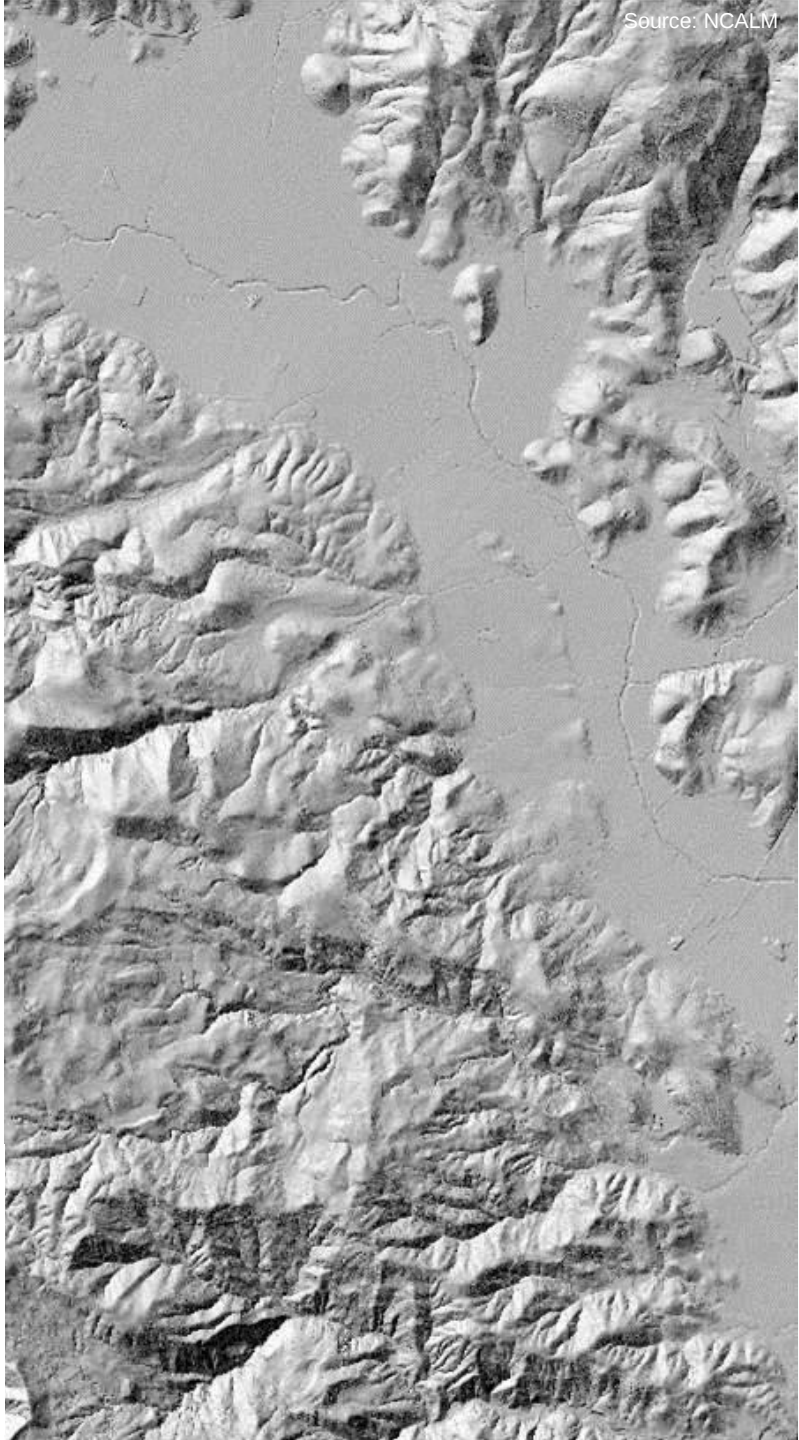
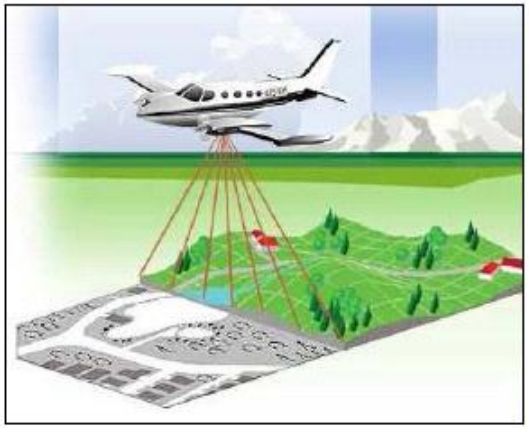
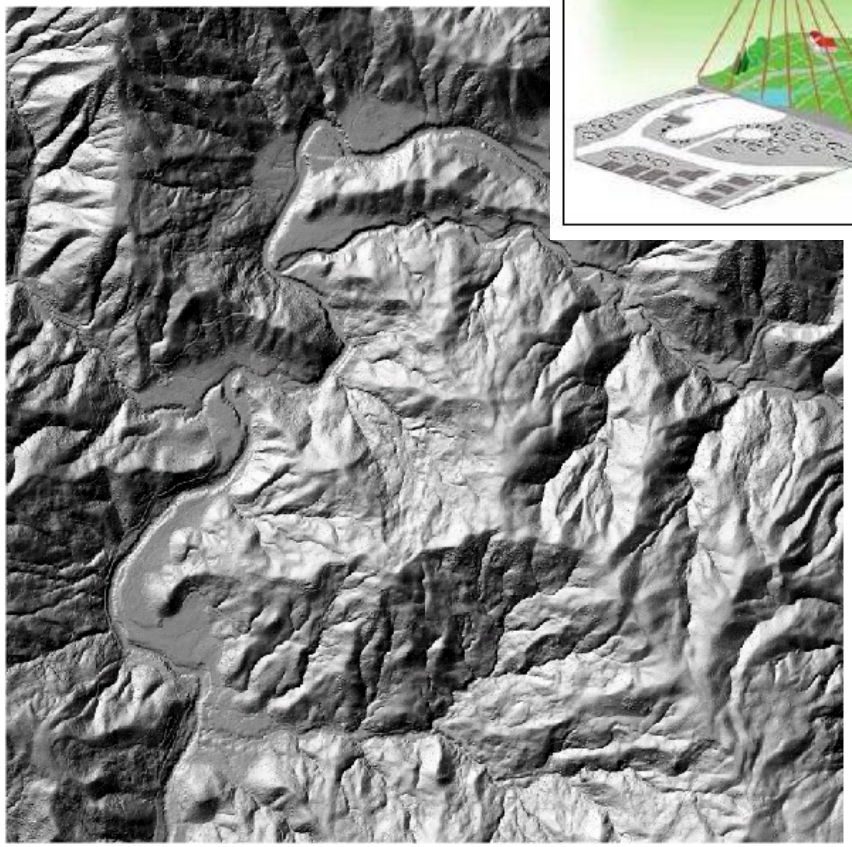
Nonlinear diffusion and geodesic paths for automatic channel network and geomorphic feature extraction from lidar

Paola Passalacqua
and many collaborators

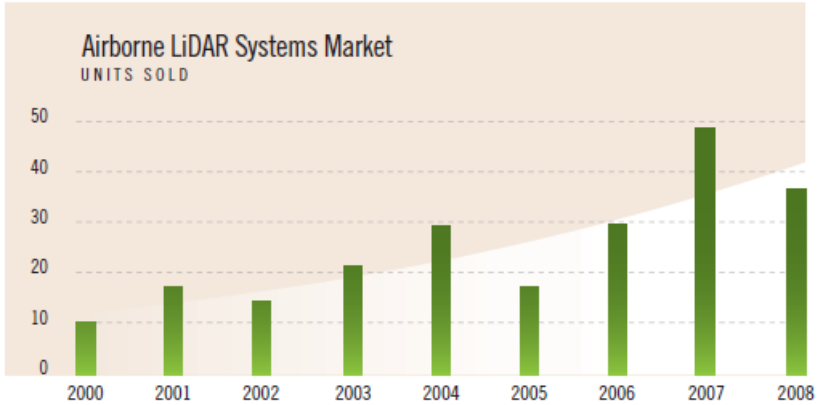
GSA 2011







Lidar technology provides detailed landscape information. How do we extract it?

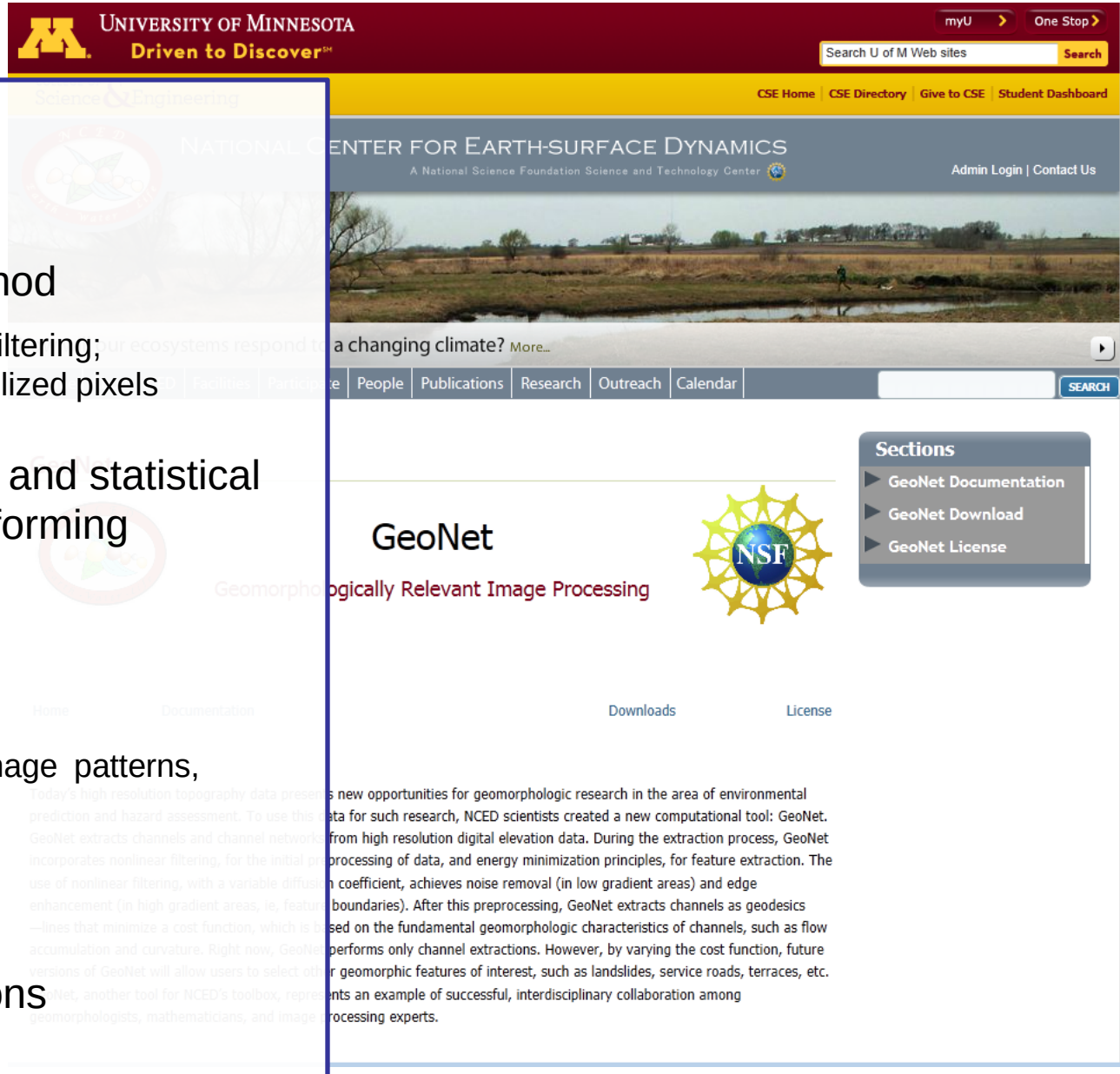


"The LiDAR market is growing all around the world, but LiDAR handling software is not and there is a void in LiDAR processing software."
Richard Vincent –Virtual Geomatics

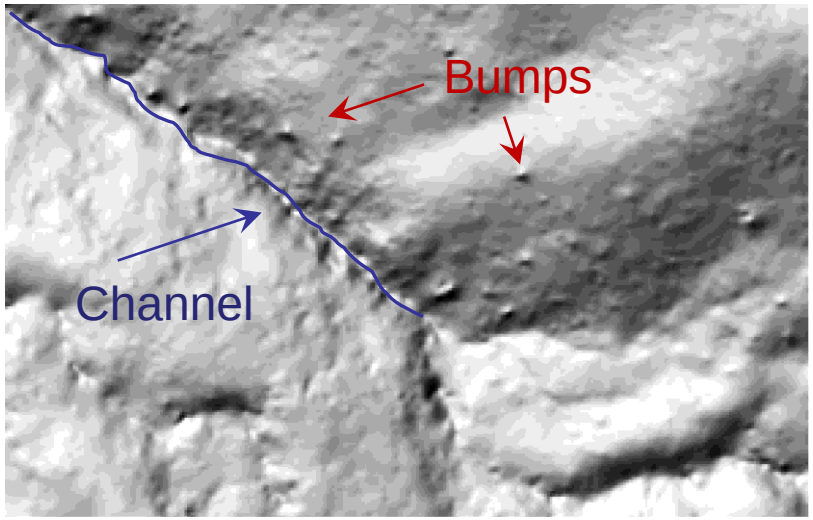
GeoNet: NCED toolbox for channel network extraction

Roadmap

- Channel extraction method
  - Linear versus nonlinear filtering;
  - Skeleton of likely channelized pixels
  - Geodesic curves;
- Exploring the geometric and statistical signature of landscape forming processes
  - Channel initiation
  - Channel disruptions
  - Channel morphology
  - Co-dependence of drainage patterns, vegetation and climate
- New release features
- Summary and conclusions



Data pre-processing



Scale of features of interest
vs.
small scale variability

A *smoothing* filter is applied on the original data to remove '*noise*' (observational noise or irregularities at scales smaller than the scales of interest).

Linear filtering

A popular smoothing filter is the Gaussian kernel:

$$h(x, y, t) = h_0(x, y) * g(x, y; t)$$

* denotes the convolution operation and G(x,y;t) is a Gaussian kernel of standard deviation t, centered at location (x,y):

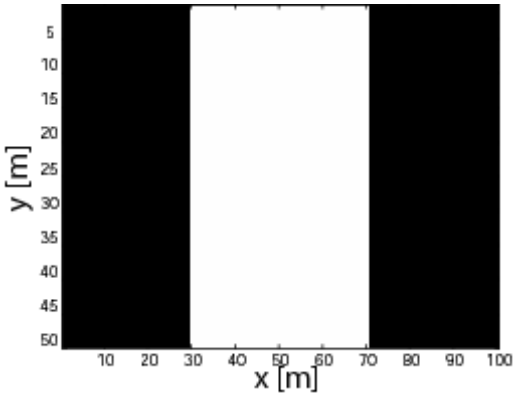
$$g_{x,y,t}(u, v) = \frac{1}{2\pi t} \exp\left[-\frac{(u-x)^2 + (v-y)^2}{2t} \right]$$

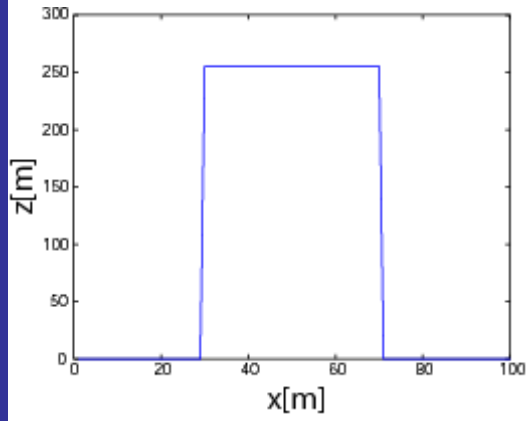
This family of coarsened landscapes may be seen as solutions of the linear heat equation [*Koenderink*, 1984]:

$$\frac{\partial h}{\partial t}(x, y, t) = \nabla \cdot (c \nabla h) = c \nabla^2 h$$

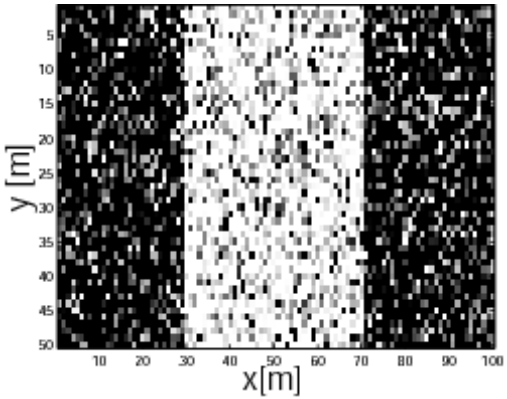
What is the effect of linear filtering?

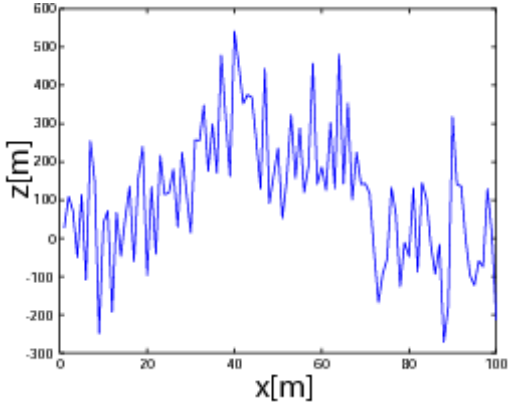
Original data



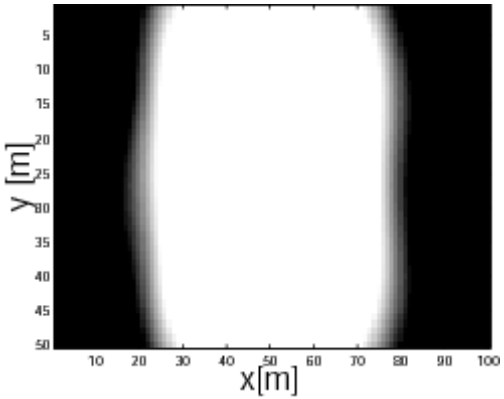


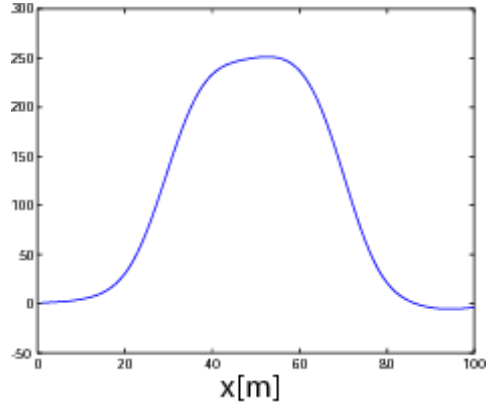
Original data with noise





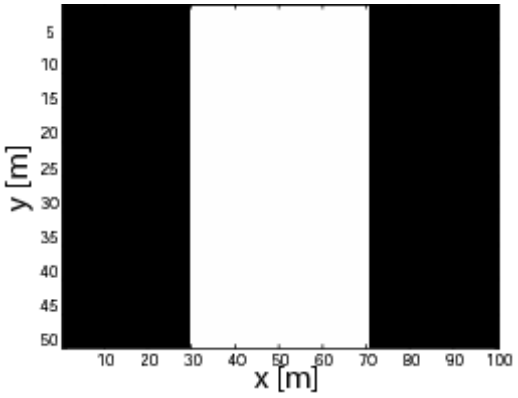
Gaussian filtering σ = 7

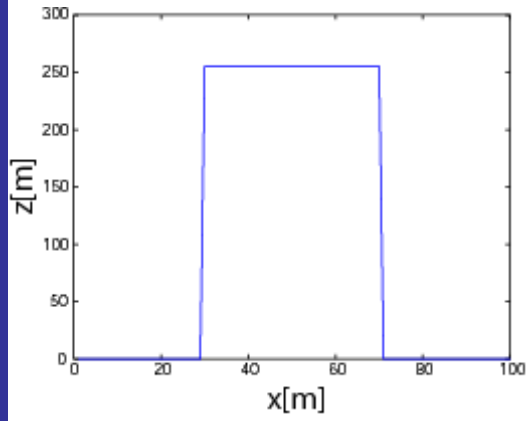




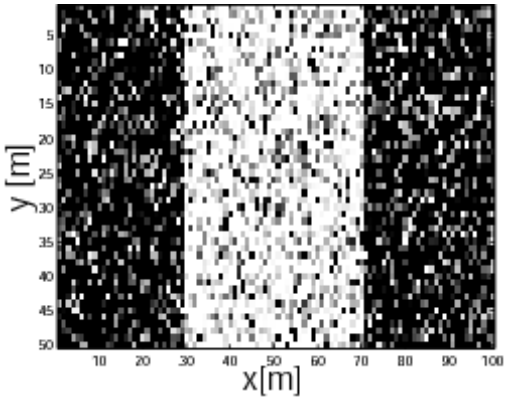
What is the effect of linear filtering?

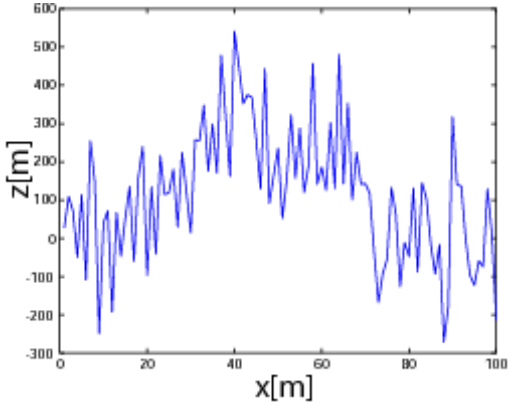
Original data



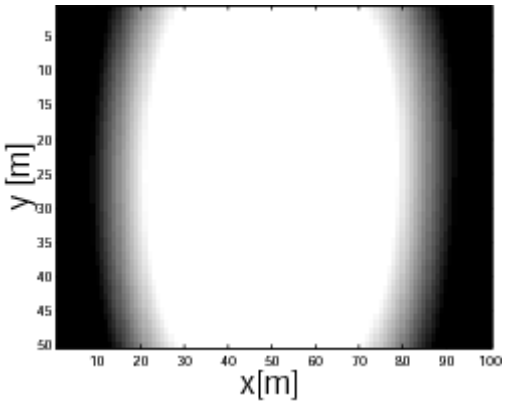


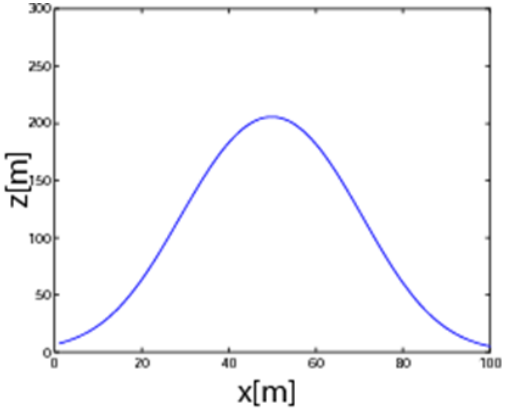
Original data with noise





Gaussian filtering σ = 14





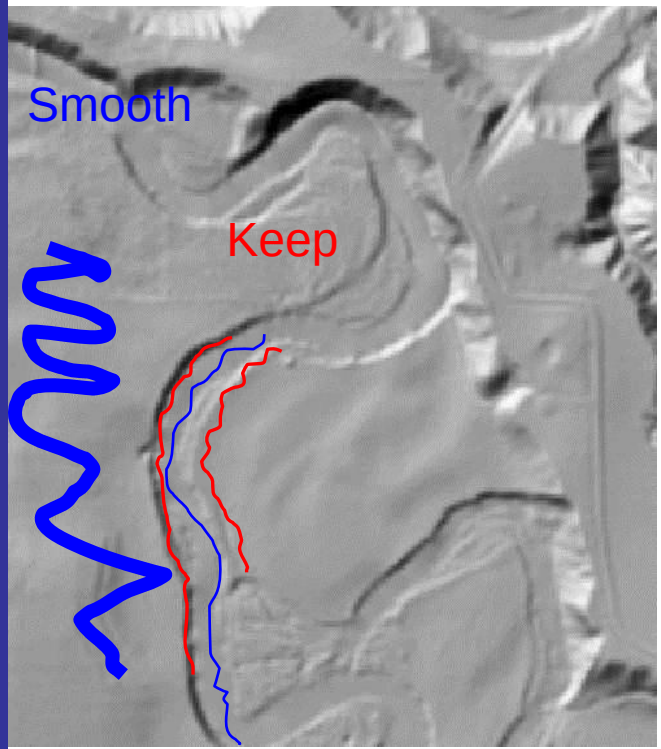
Gaussian filtering is isotropic and does not respect the natural boundaries of the features.

Perona-Malik nonlinear filtering

Perona and Malik [1990]: preferential interregion smoothing rather than intraregion.

Nonlinear diffusion filtering type with a diffusion coefficient chosen as a suitable function of space and time:

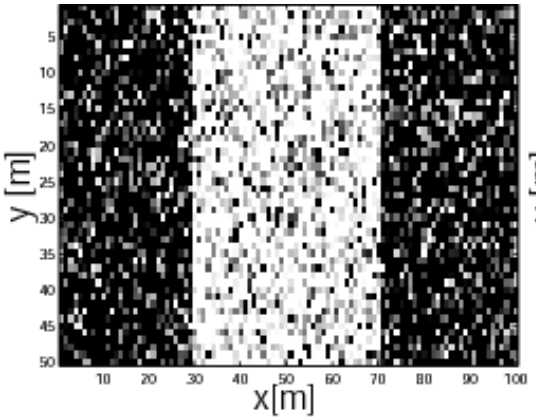
$$\partial_t h(x,y,t) = \nabla \cdot \left(c(x,y,t) \nabla h \right) = c(x,y,t) \Delta h + \nabla c \cdot \nabla h$$



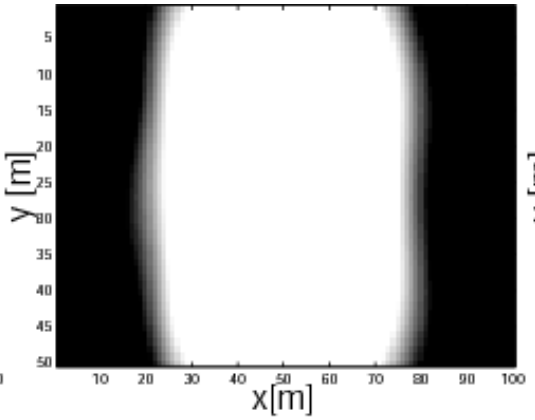
$$c = \frac{1}{1 + \left(|\nabla h| / \lambda \right)^2}$$

Nonlinear filtering

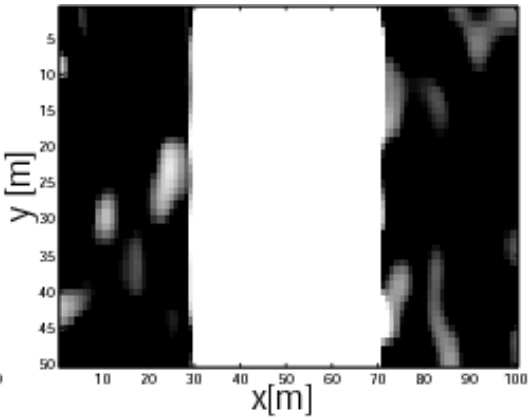
Original data with noise

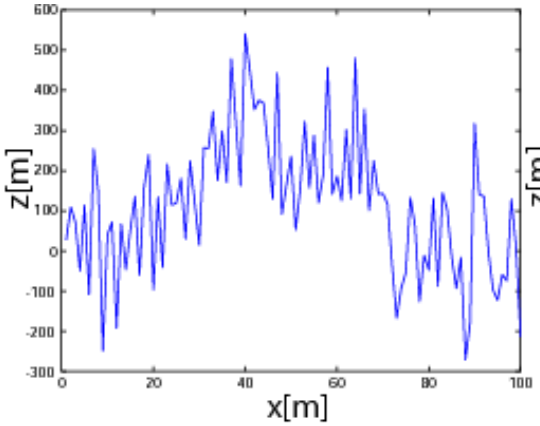


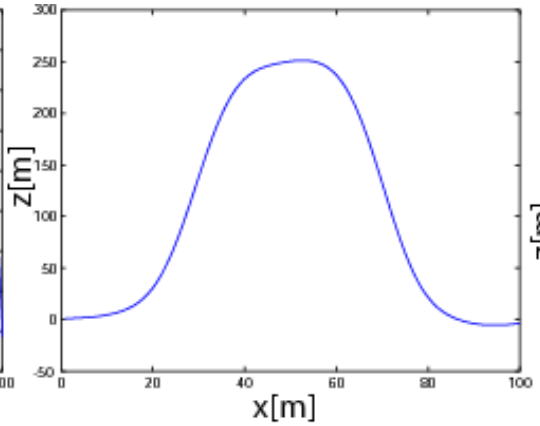
Gaussian filtering σ = 7

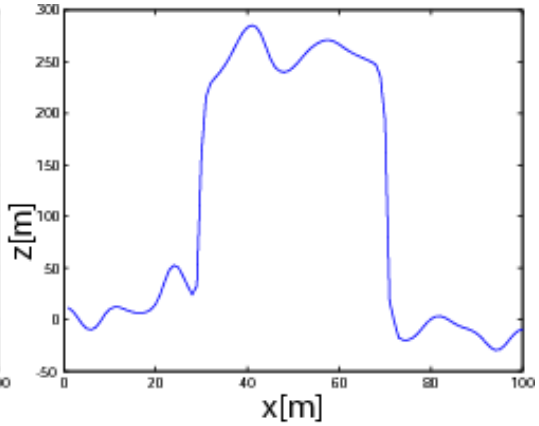


Perona-Malik t = 50









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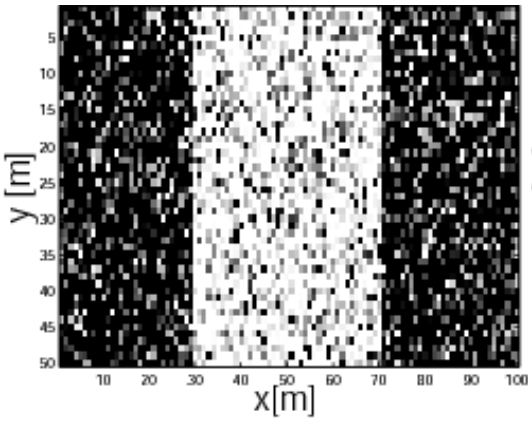
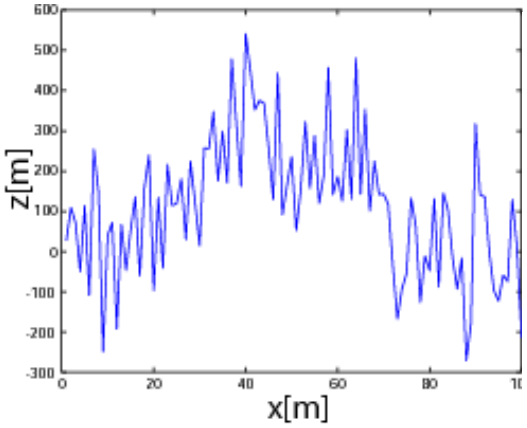
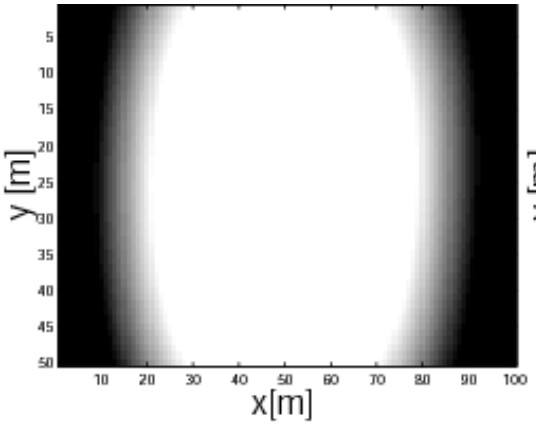
Nonlinear filtering

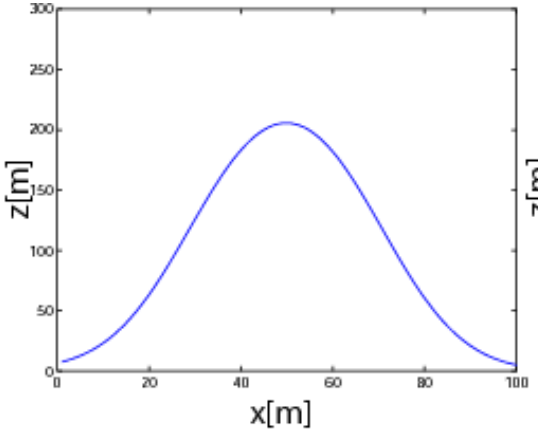
Original data with noise



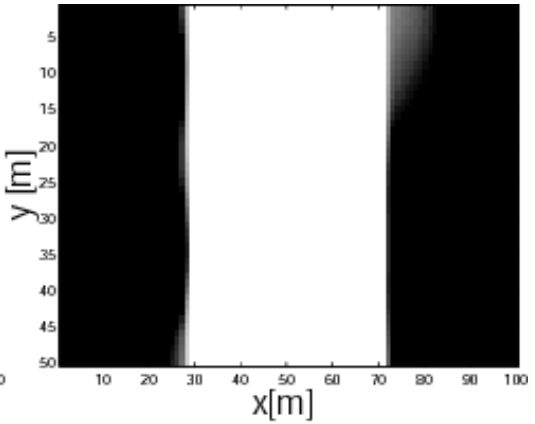


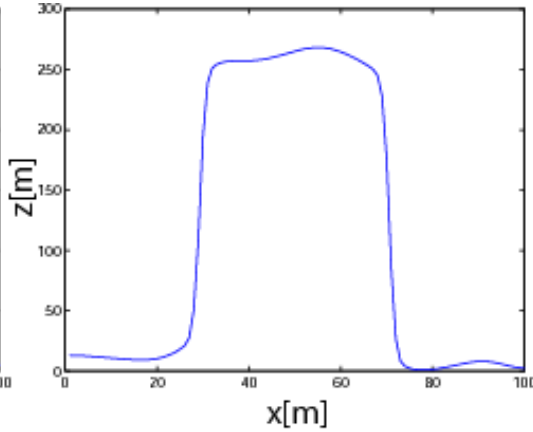
Gaussian filtering σ = 14





Perona-Malik t = 200





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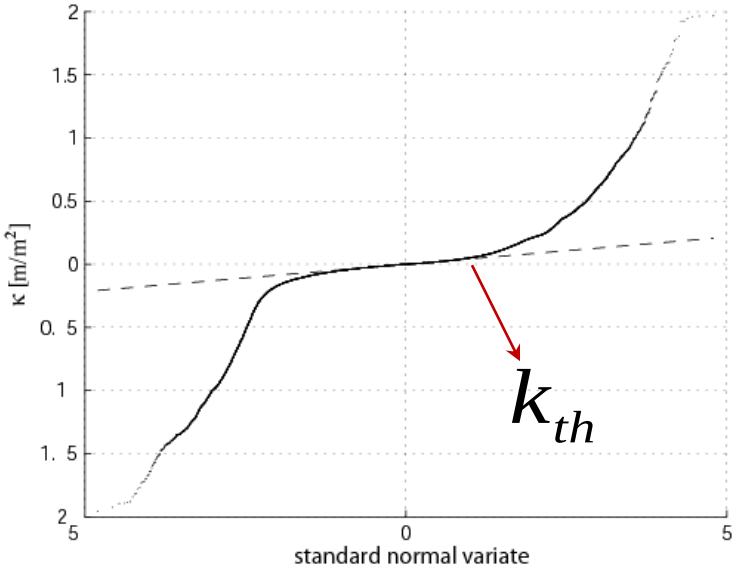
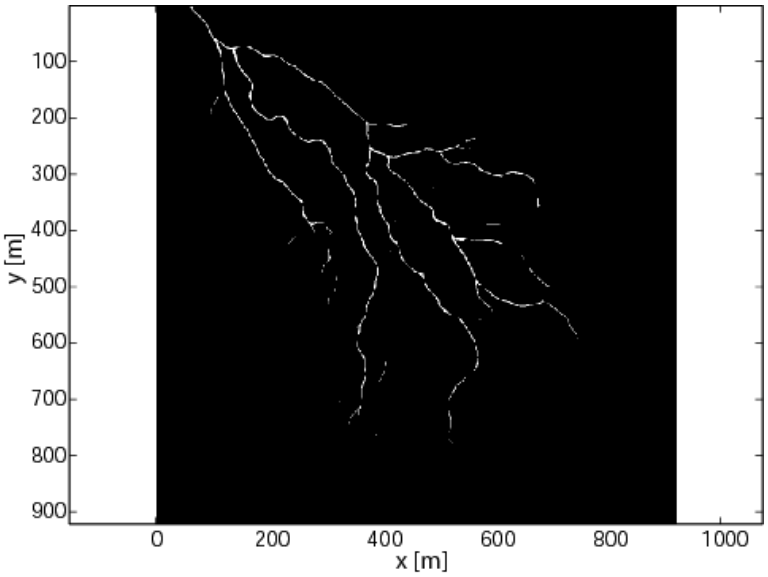
Statistical signature of geomorphic transitions

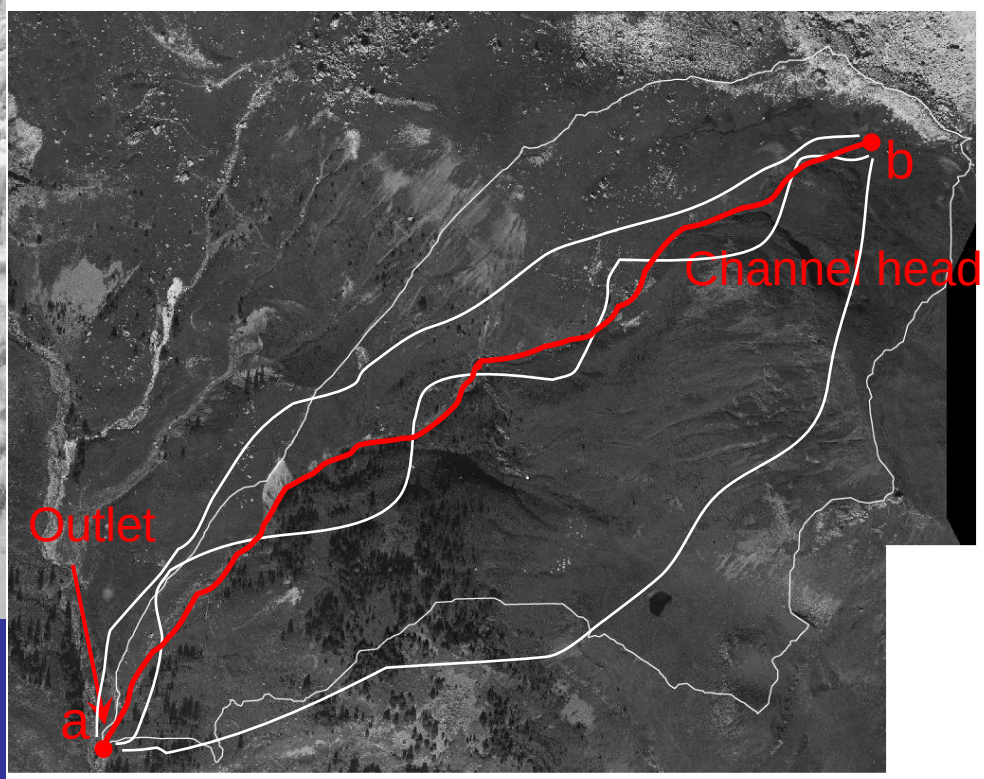




Quantile-quantile plot: Deviation from a straight line indicates a deviation of the pdf from Gaussian and can be interpreted as transition from hillslope to valley [Lashermes et al,. 2007].

Skeleton of likely channelized pixels: binary matrix where 1 is assigned to pixels with curvature above threshold.

Channel extraction: geodesics



What makes the channel special?

The *cost function* ψ represents the cost of traveling between point a and point b in terms of a function of area (A), slope (S), curvature (κ) and skeleton (Skel):

$$\psi = \frac{1}{f(A, S, \kappa, Skel)} \quad e.g., \frac{1}{\alpha \cdot A + \delta \cdot \kappa}$$

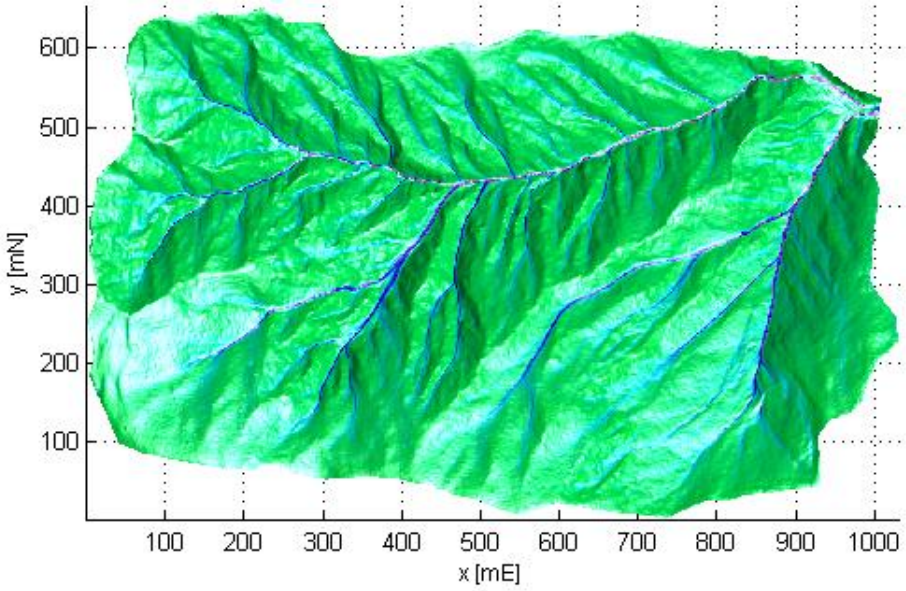
The curve with minimum cost is the geodesic curve:

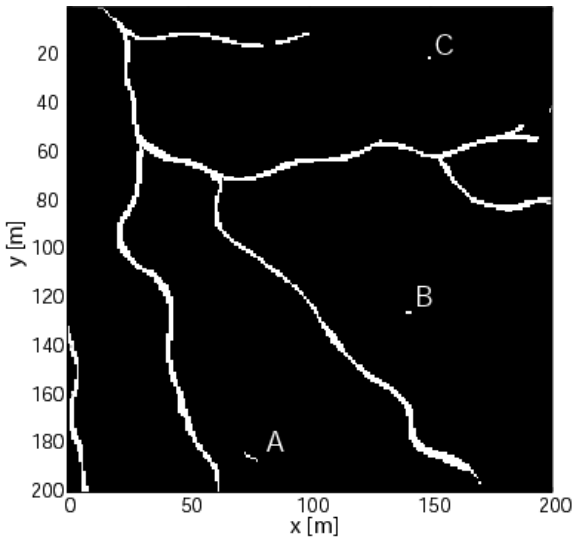
$$g(a,b) := \arg\left(\min_{C \in \Omega} \int_a^b \Psi(s) ds \right)$$

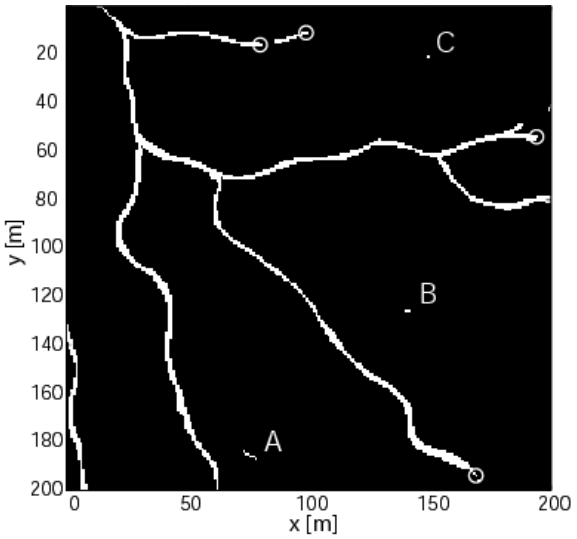
End point detection

The cost is minimum along the channels

$$\psi = \frac{1}{f(A, S, \kappa, Skel)}$$







End points are identified as the points of the skeleton at minimum geodesic distance from the outlet.

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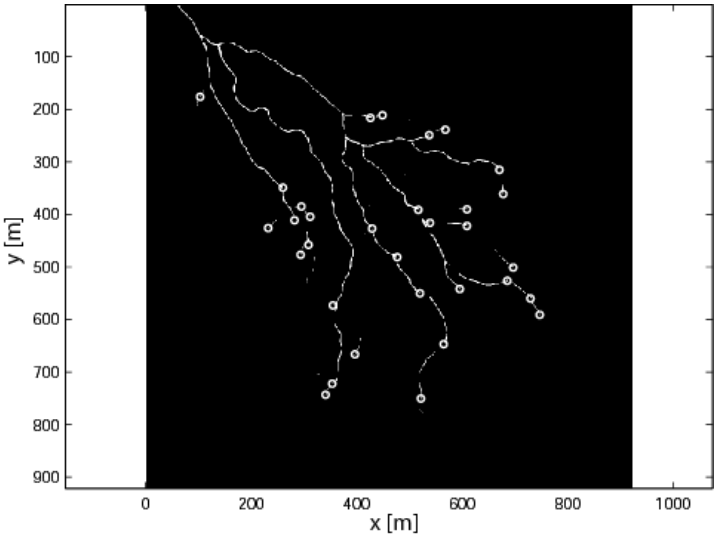
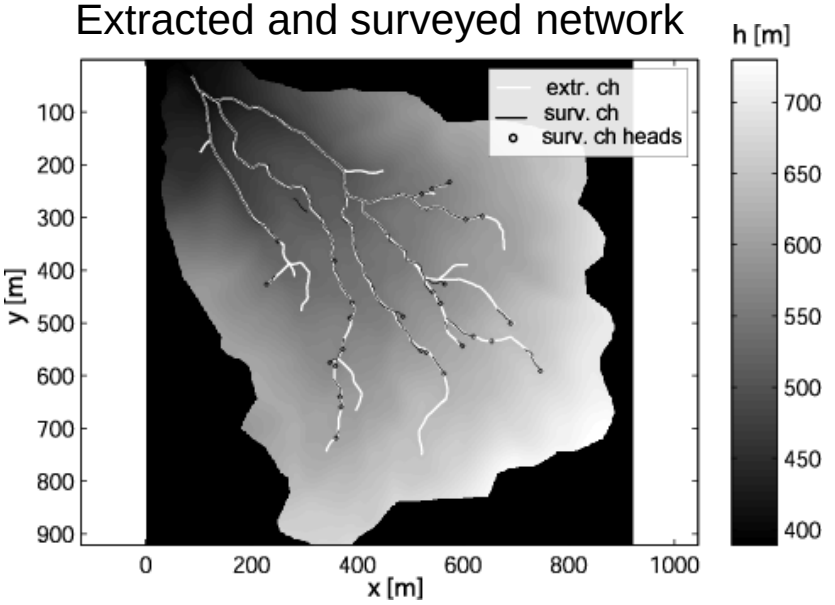
Channel extraction

Skeleton with end points



Extracted and surveyed network



The curve with minimum cost is the geodesic curve:

$$g(a,b) := \arg\left(\min_{C \in \Omega} \int_a^b \Psi(s)\,ds \right)$$

Channels are traced by gradient descent on the geodesic distance.

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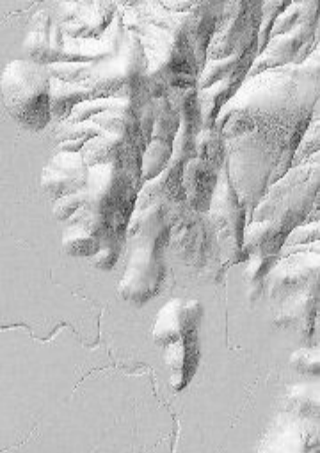
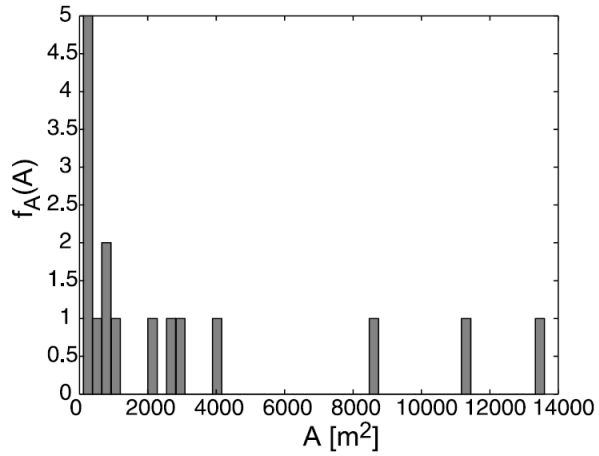
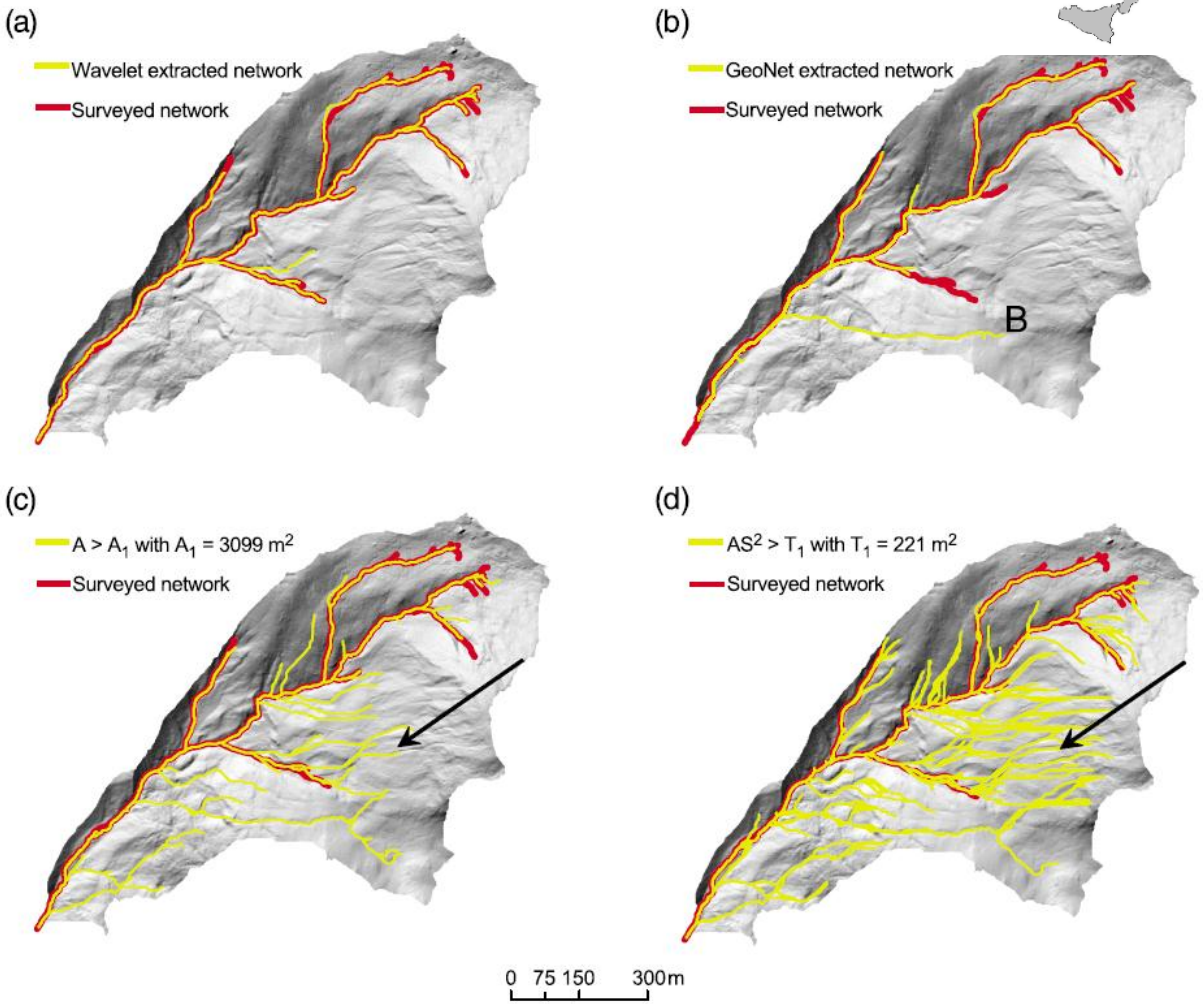


Applications: Channel initiation

With Paolo Tarolli, Efi Foufoula-Georgiou





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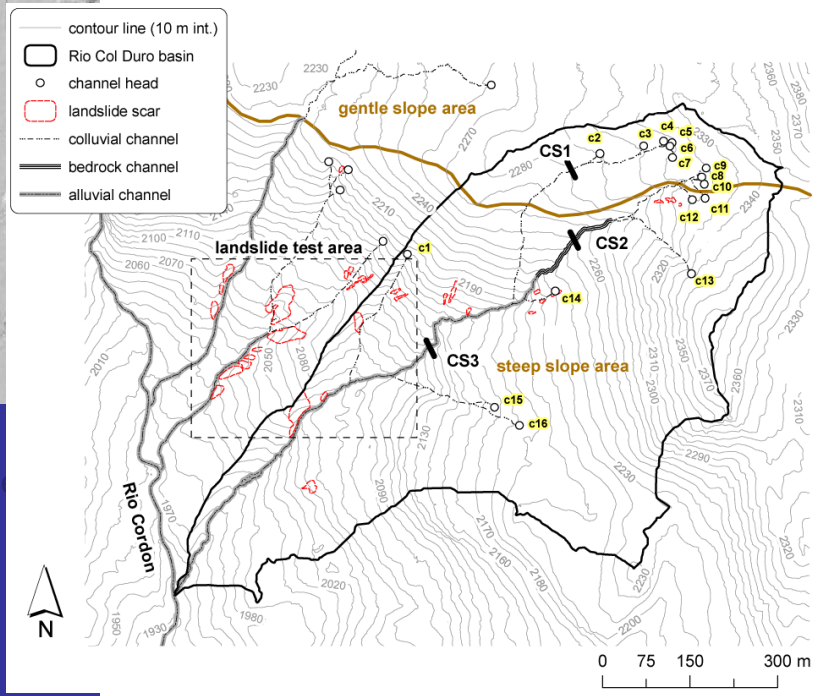
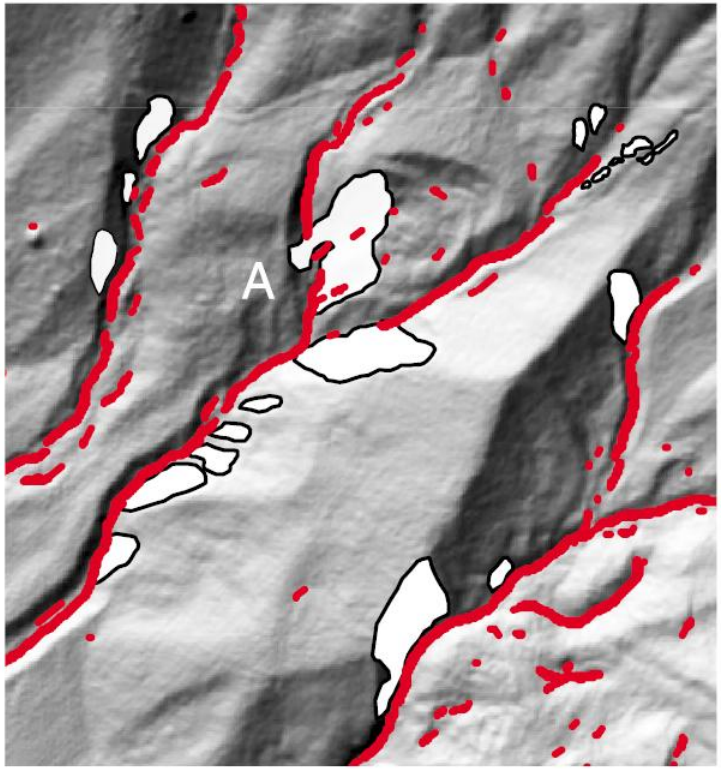
Applications: Channel disruptions

With Paolo Tarolli, Efi Foufoula-Georgiou





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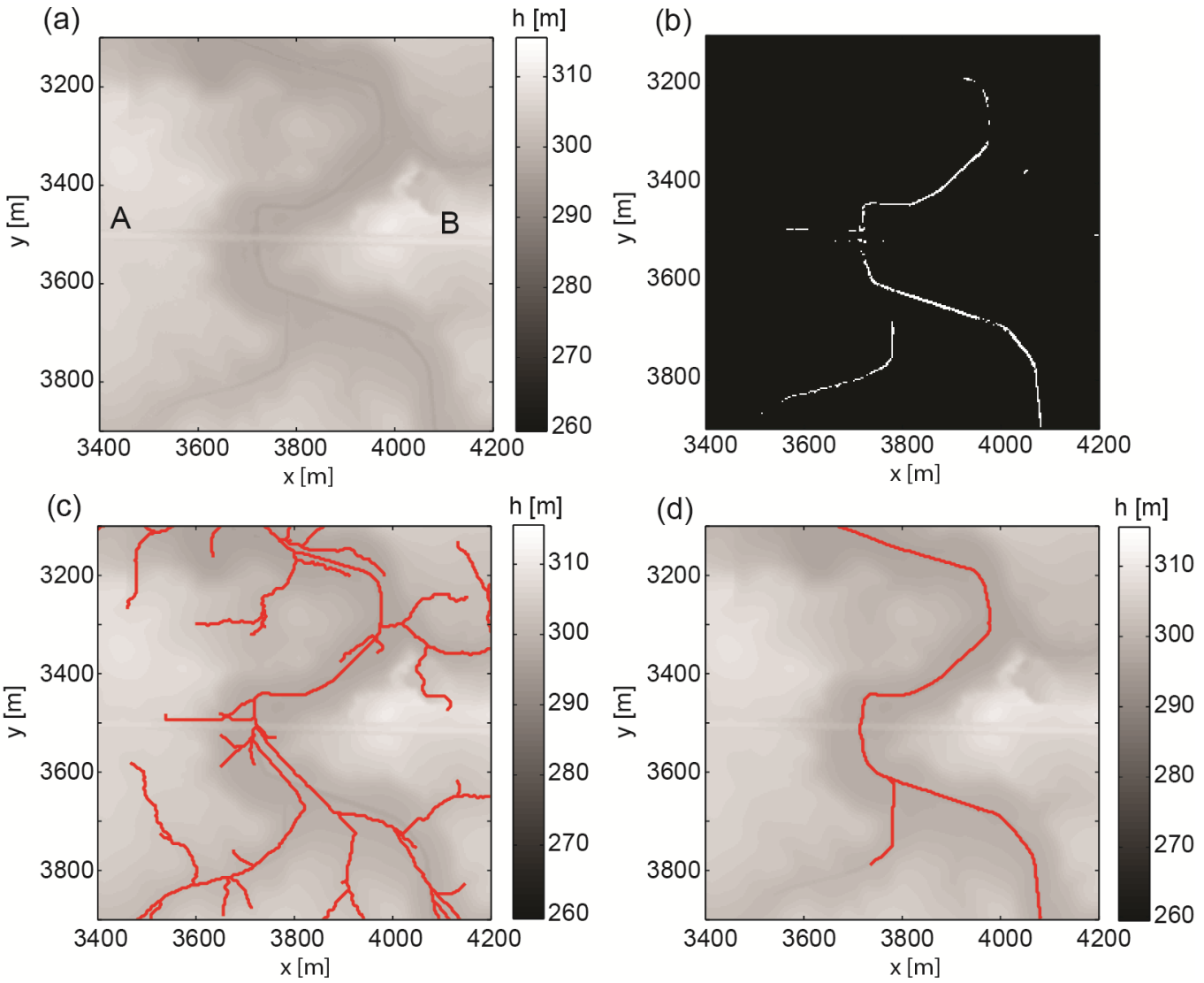
Applications: Flat lands and channel morphology

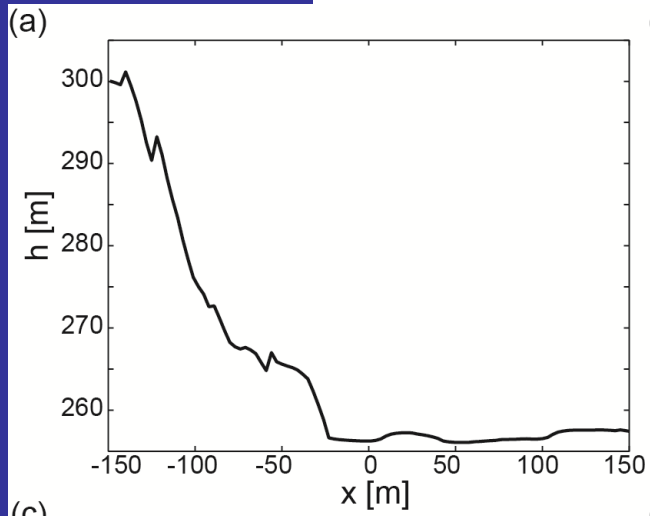
With Patrick Belmont, Efi Foufoula-Georgiou

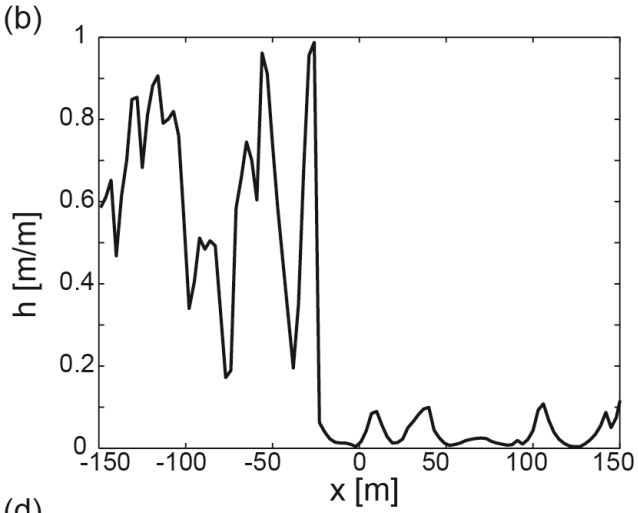


Passalacqua, P., P. Belmont, and E. Foufoula-Georgiou, in review.

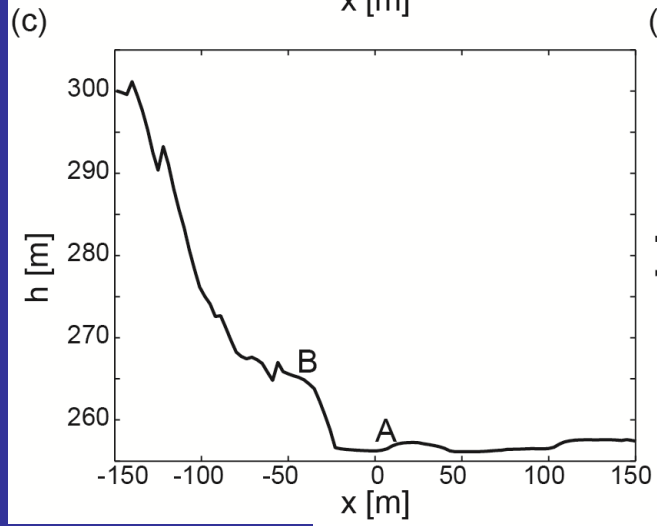
Applications: Flat lands and channel morphology

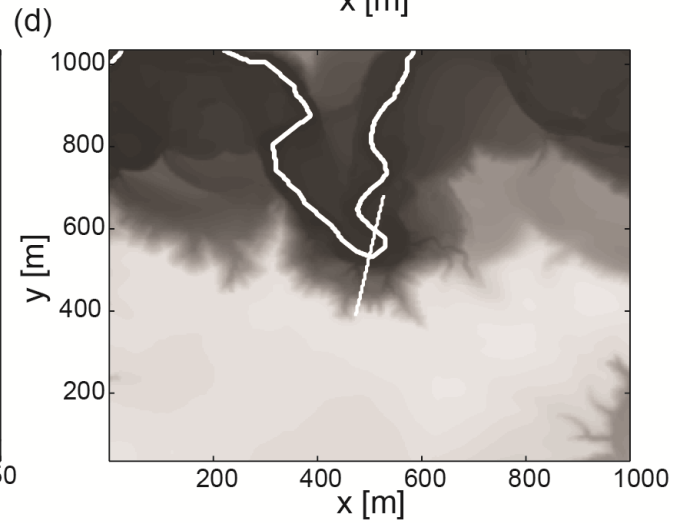
With Patrick Belmont, Efi Foufoula-Georgiou





Source: P. Belmont



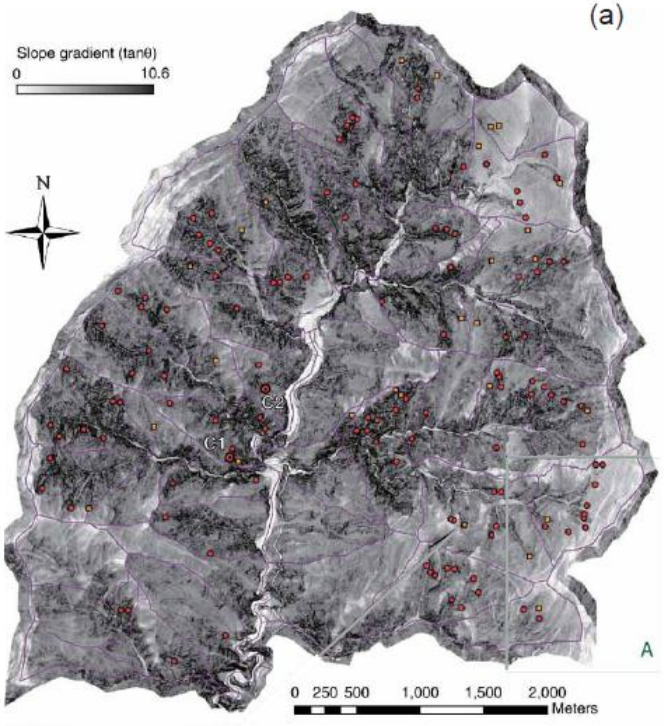


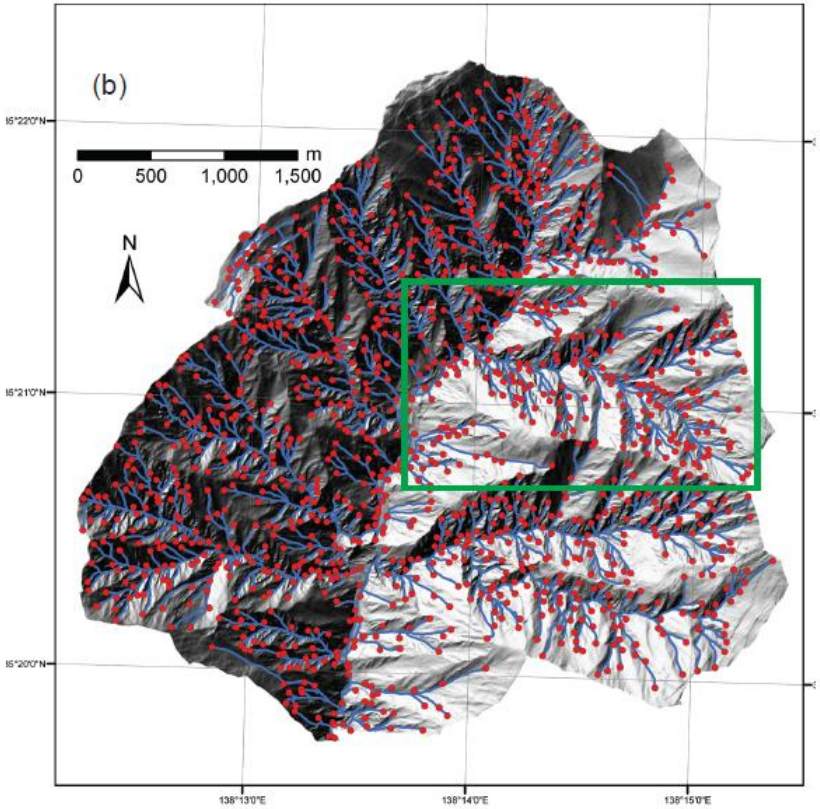
Source: C. Jennings

Passalacqua, P., P. Belmont, and E. Foufoula-Georgiou, in review.

Applications: Co-dependence of drainage patterns, vegetation and climate

With Colin Stark, Harish Sangireddy



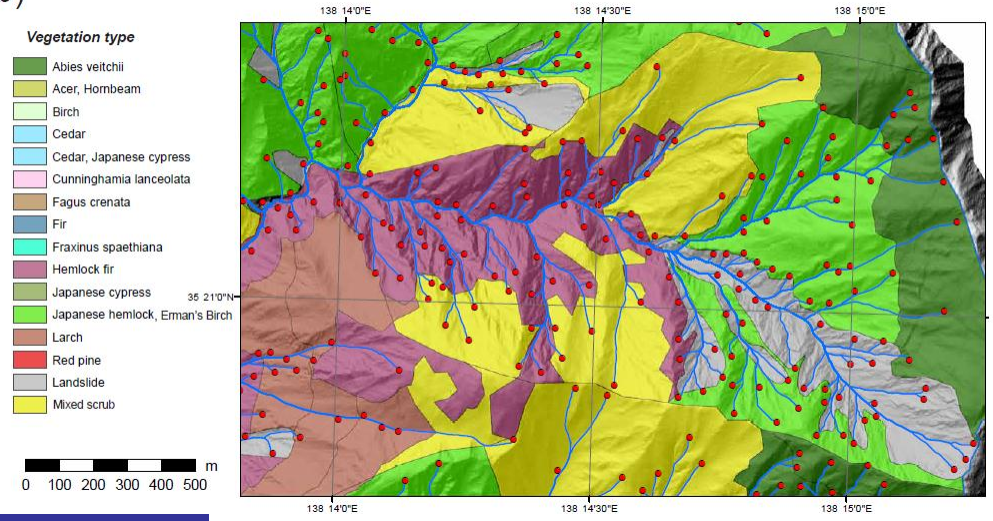


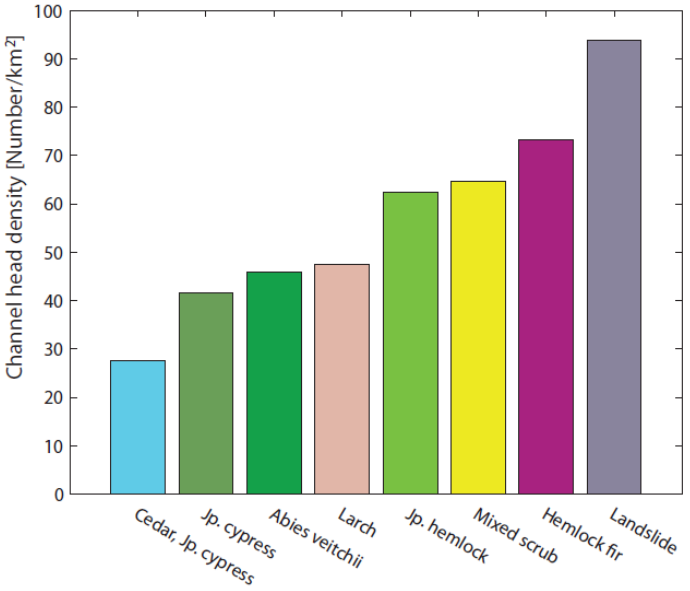
Applications: Co-dependence of drainage patterns, vegetation and climate

With Colin Stark, Harish Sangireddy

(a)

(b)





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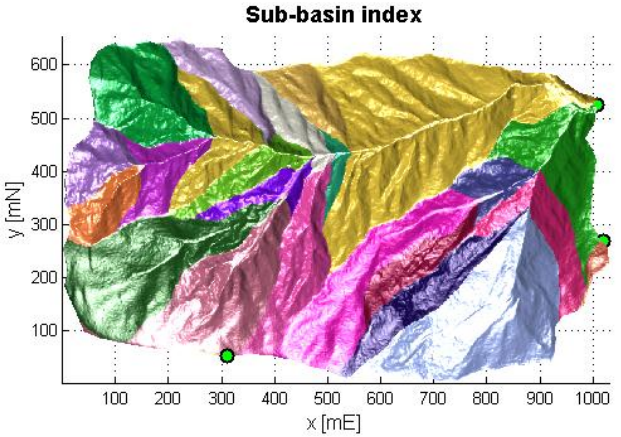
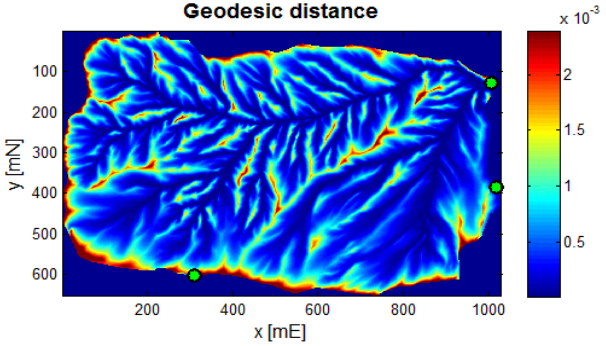
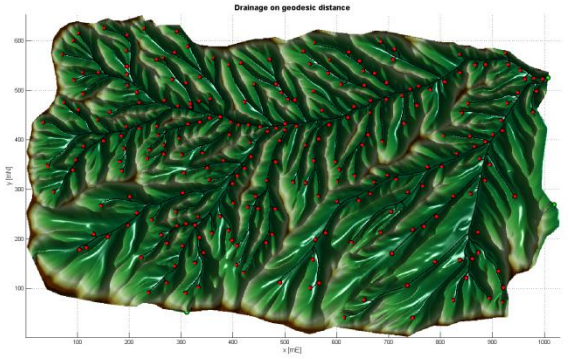
- Basin and sub-basin identification
- Better channel head detection
- Better channel path delineation
- Faster and more memory efficient code
- Easier installation
- New improved user interface
- Easier user customization
- Better visualization now 2D and 3D
- Better GIS file and Metadata handling
- Bug fixes
- Better documentation
- More demo DTMs







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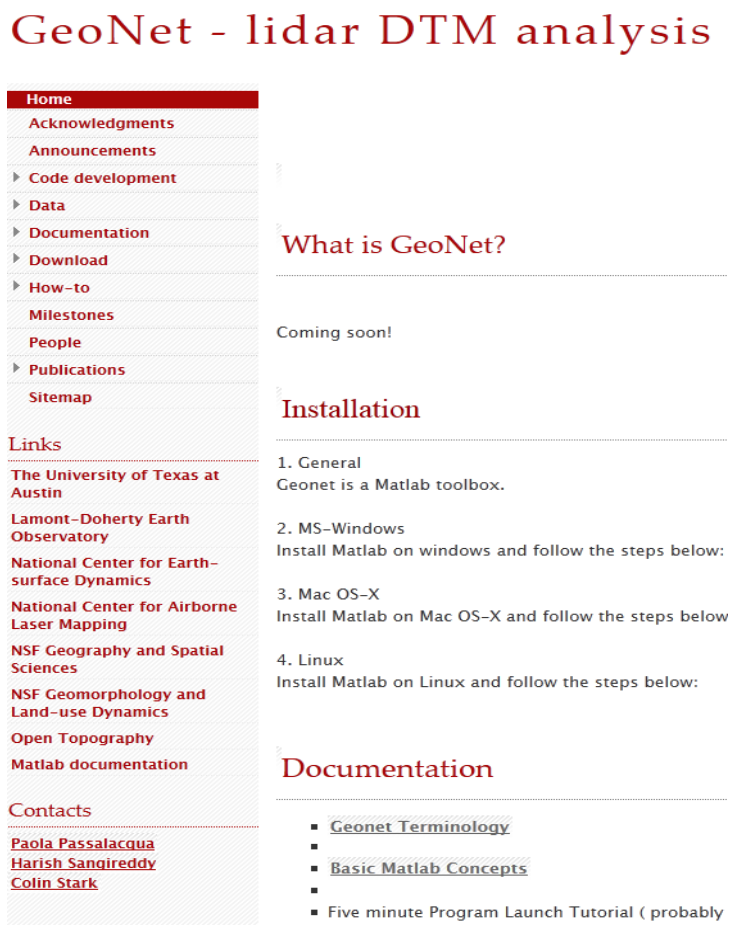
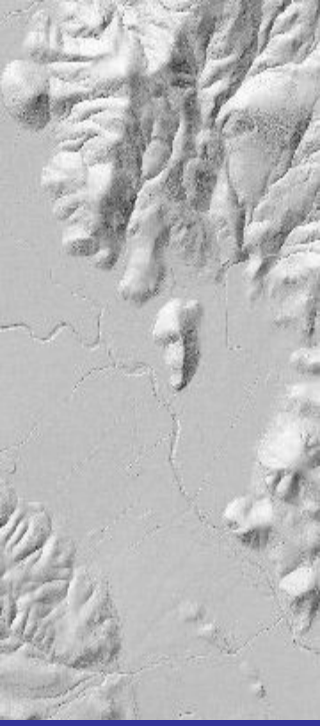
Website at sites.google.com/site/geonethome/

(online at release date)





Summary and conclusions

- GeoNet combines nonlinear diffusion and geodesic paths;
- Nonlinear filtering preserves the location of features of interest;
- Geodesic paths allow a global robust extraction of channels (not affected by local noise, roads, etc.);
- Applied to a variety of landscapes of different characteristics
- Toolbox available for free download
http://www.nced.umn.edu/content/geonet
- New release coming out in November 2011.

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