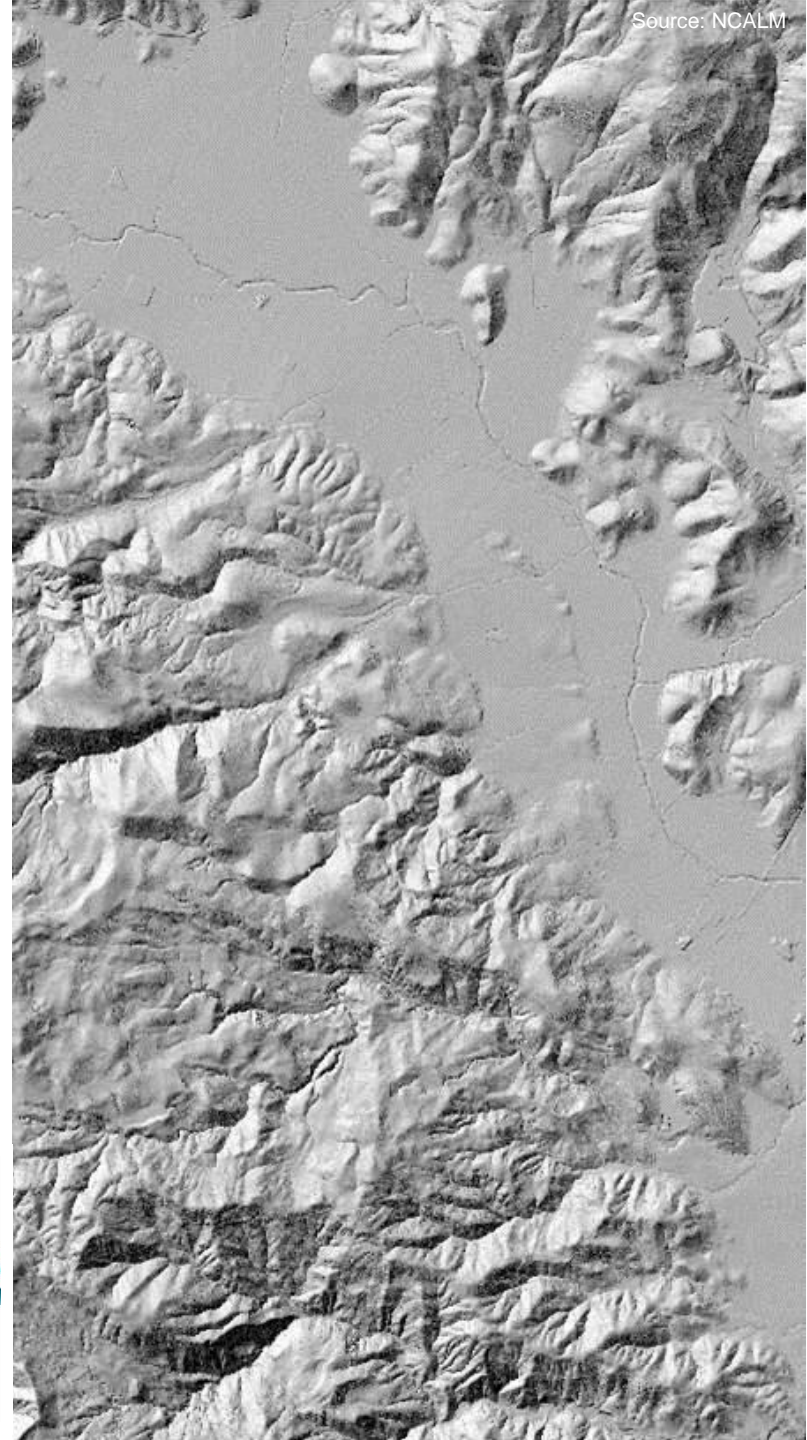
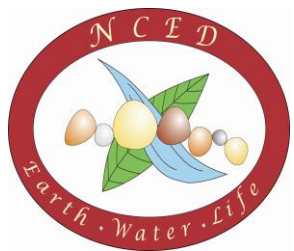
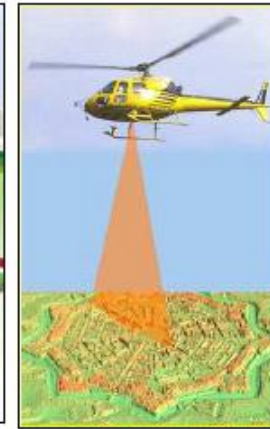
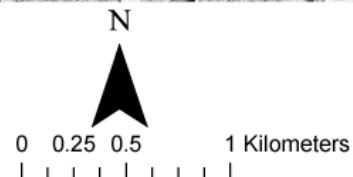
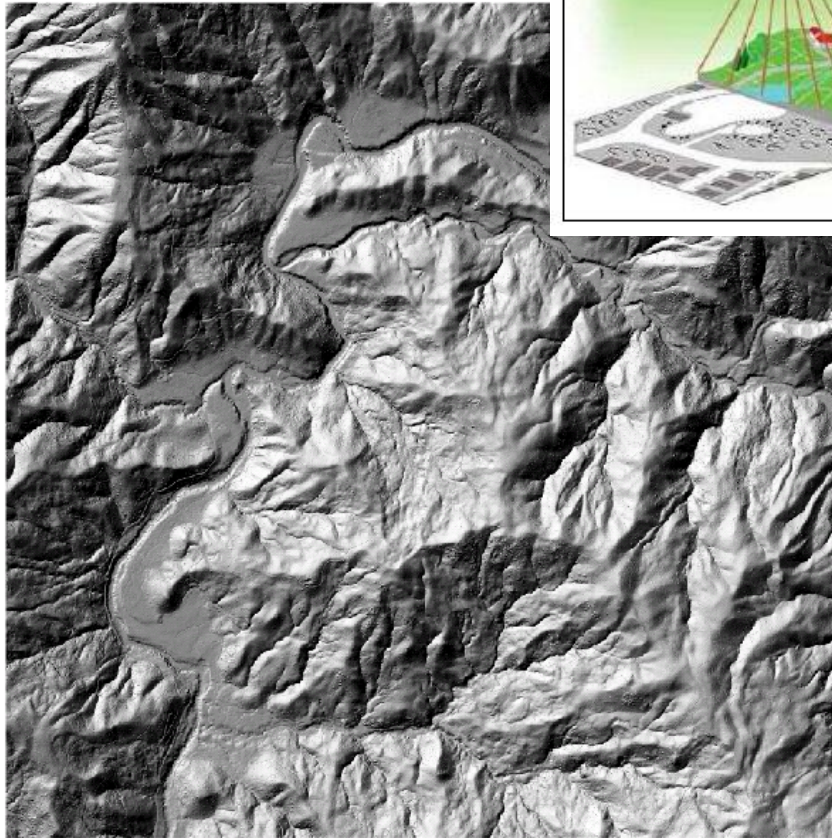


# **Nonlinear diffusion and geodesic paths for automatic channel network and geomorphic feature extraction from lidar**

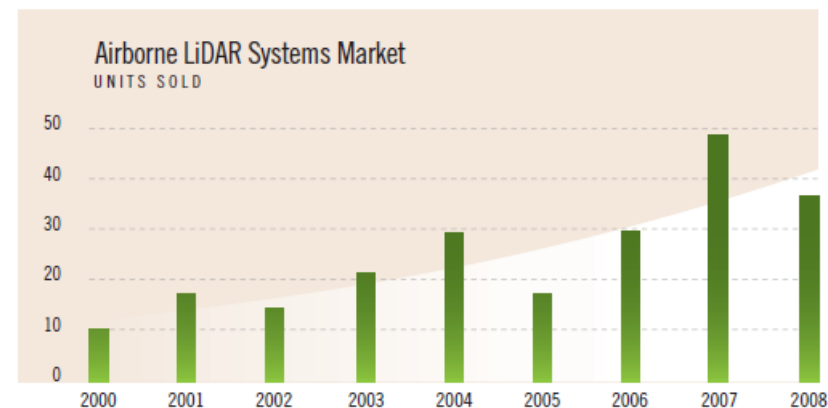
Paola Passalacqua  
and many collaborators

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



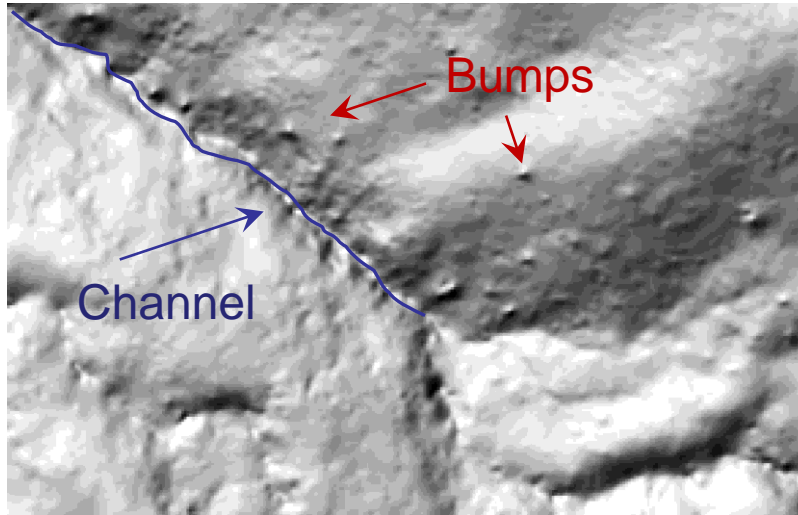
# GeoNet: NCED toolbox for channel network extraction

## 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

The screenshot shows the GeoNet website, which is part of the National Center for Earth-Surface Dynamics (NCESD). The header includes the University of Minnesota logo and the tagline "Driven to Discover". The main navigation bar features links to "CSE Home", "CSE Directory", "Give to CSE", and "Student Dashboard". The central banner displays a landscape image with a river and the text "GeoNet: Geomorphologically Relevant Image Processing". A sidebar on the right lists "Sections" including "GeoNet Documentation", "GeoNet Download", and "GeoNet License". The main content area provides a detailed description of the GeoNet toolbox, highlighting its use in channel network extraction from high-resolution digital elevation data. The text describes the process of nonlinear filtering, noise removal, and geodesic curve extraction, emphasizing the tool's role in geomorphologic research and environmental prediction.

# 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).

- Extraction method

- Linear vs. nonlinear

- Skeleton

- Geodesics

- Applications

- Channel initiation

- Channel disruptions

- Channel morphology

- Vegetation and climate

- New release

- Conclusions

# 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  $(x, y)$ :

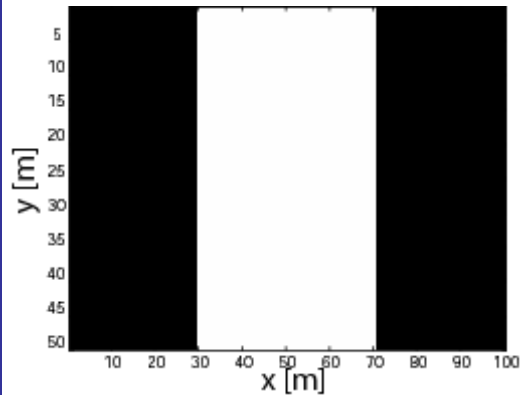
$$g_{x, y, t}(u, v) = \frac{1}{2\pi t} \exp\left[-\frac{(u-x)^2 + (v-y)^2}{2t}\right]$$

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

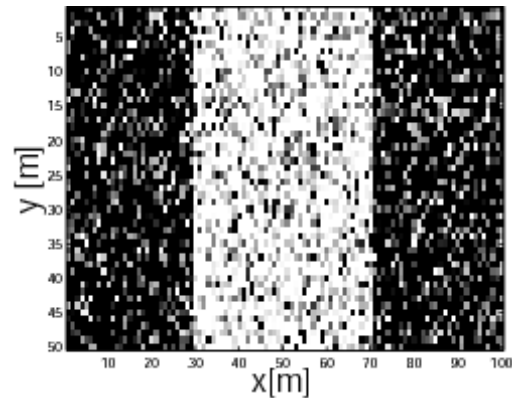
$$\frac{\partial h}{\partial t}(x, y, t) = \nabla \cdot (c \nabla h) = c \nabla^2 h$$

# What is the effect of linear filtering?

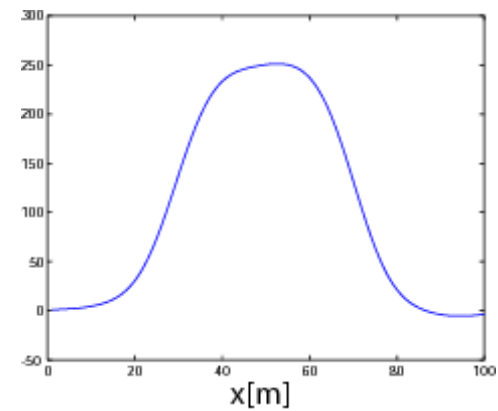
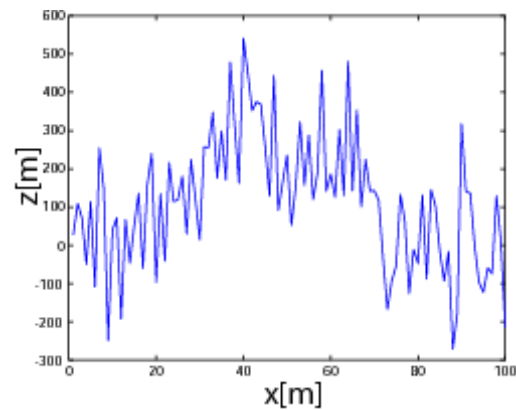
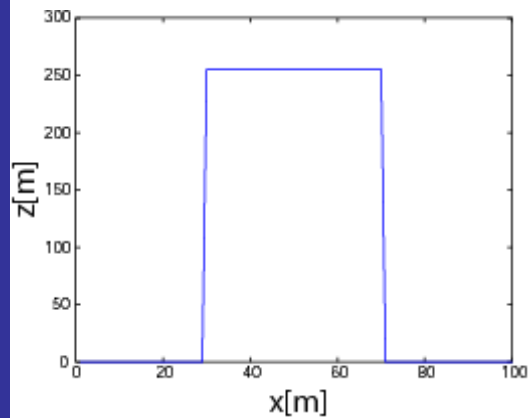
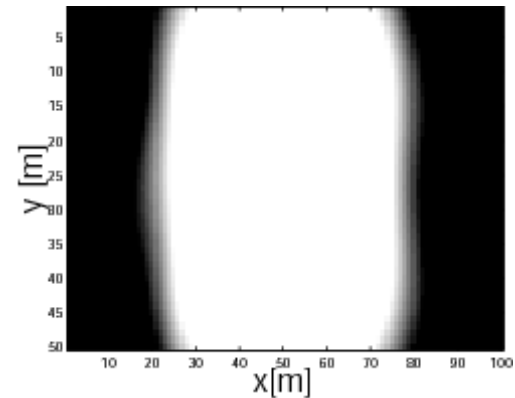
Original data



Original data with noise

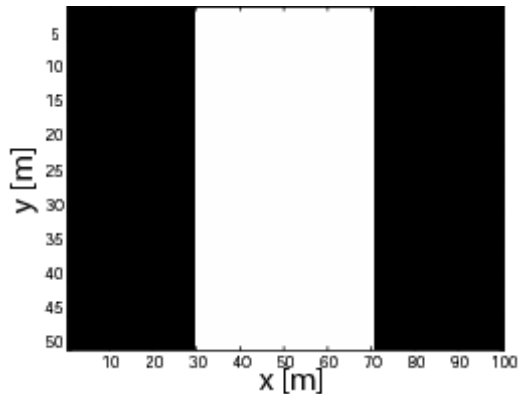


Gaussian filtering  $\sigma = 7$

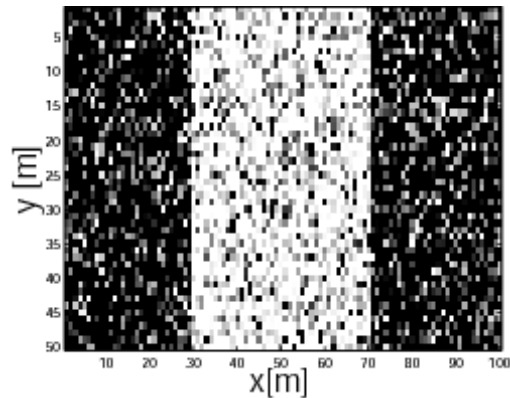


# What is the effect of linear filtering?

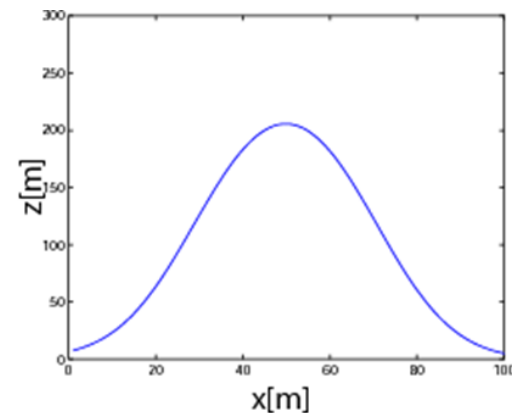
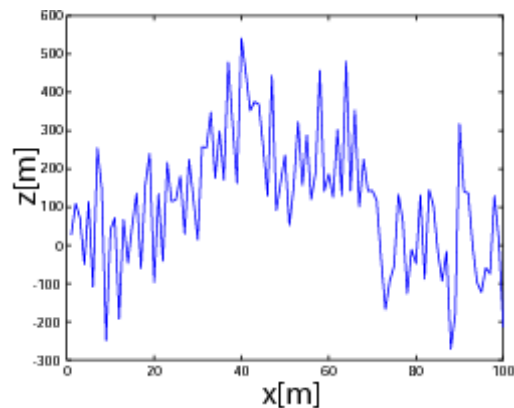
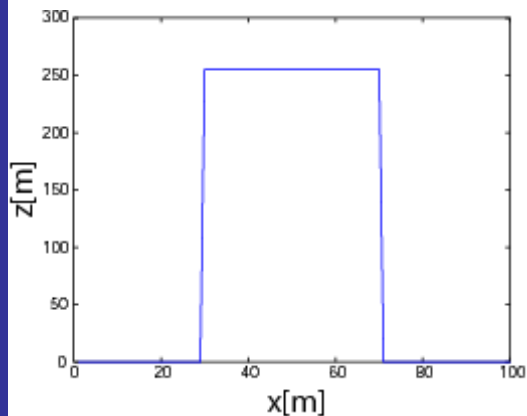
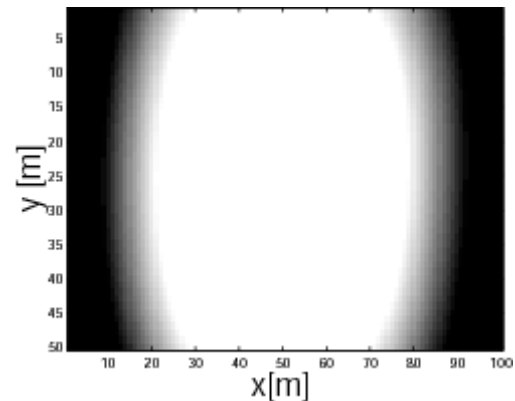
Original data



Original data with noise



Gaussian filtering  $\sigma = 14$



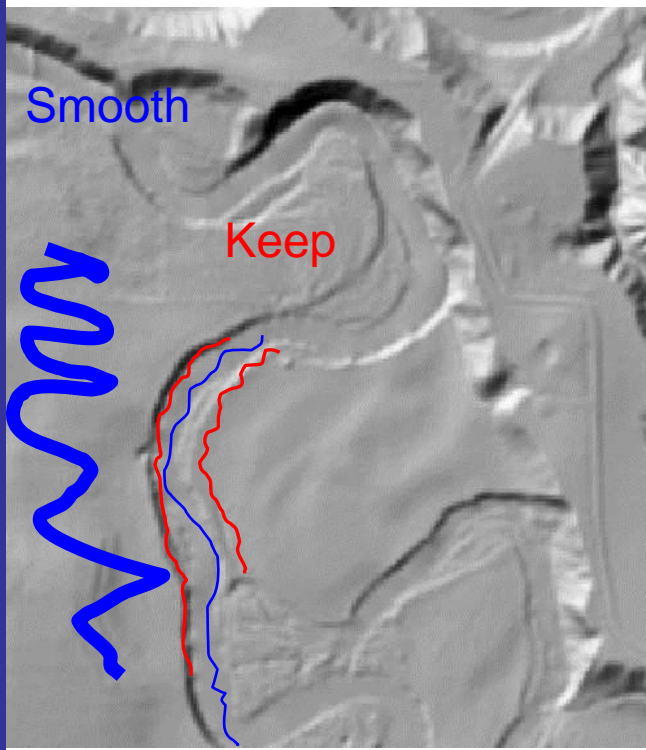
Gaussian filtering is isotropic and does not respect the natural boundaries of the features.

# 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:

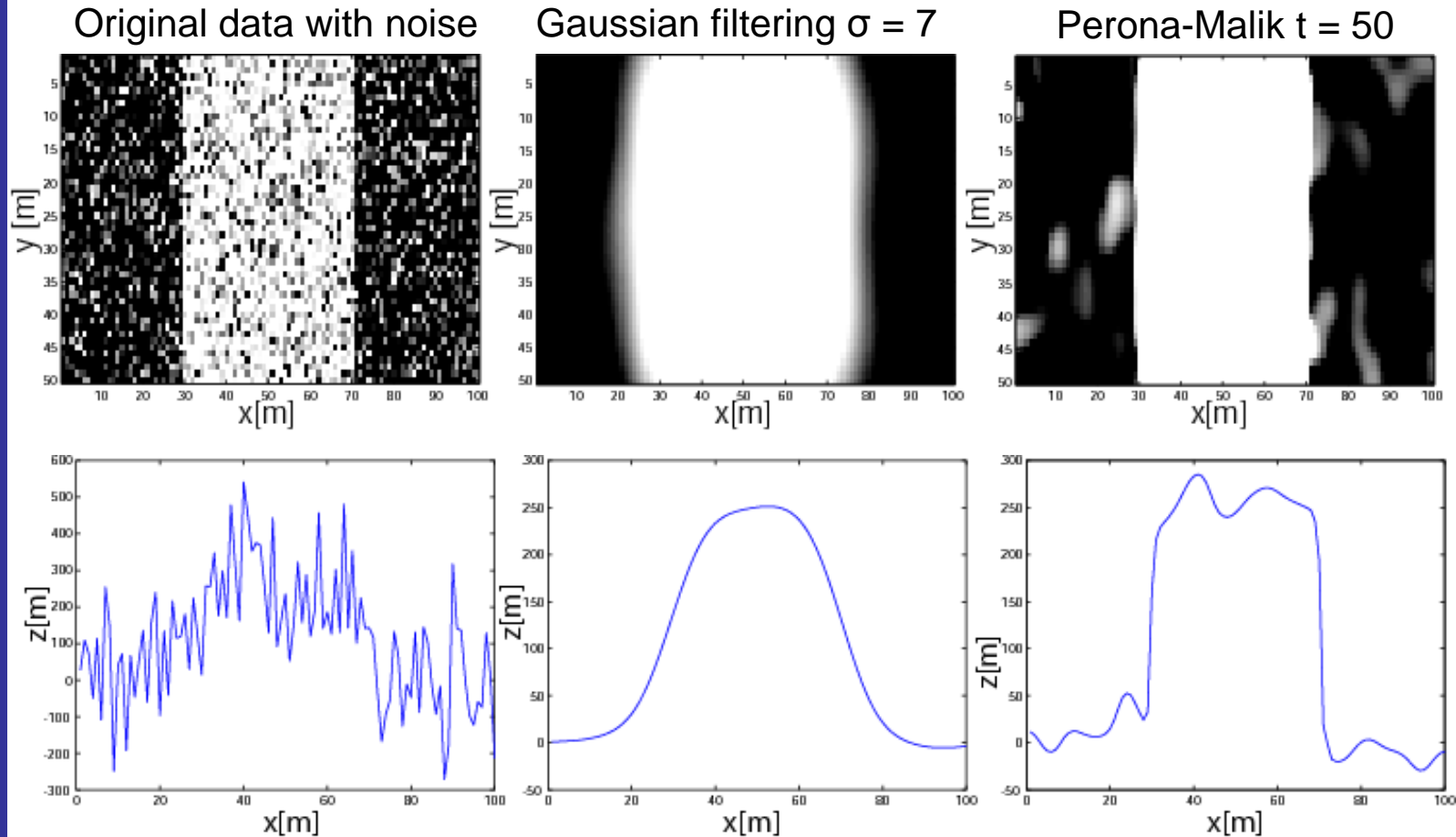
$$\partial_t h(x, y, t) = \nabla \cdot (c(x, y, t) \nabla h) = c(x, y, t) \Delta h + \nabla c \cdot \nabla h$$



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

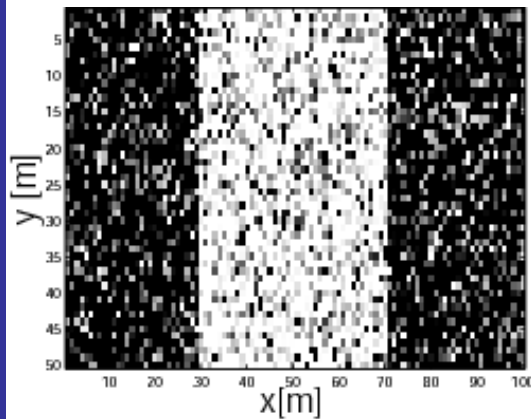


# Nonlinear filtering

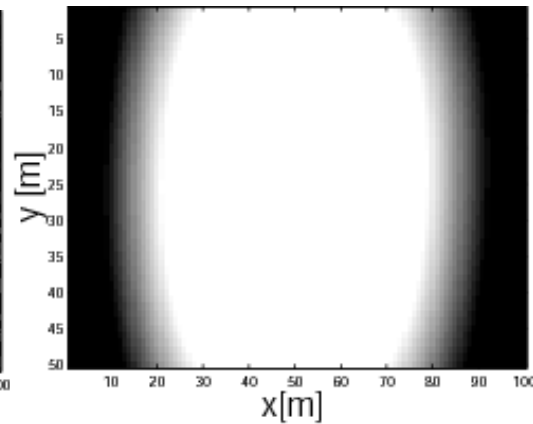


# Nonlinear filtering

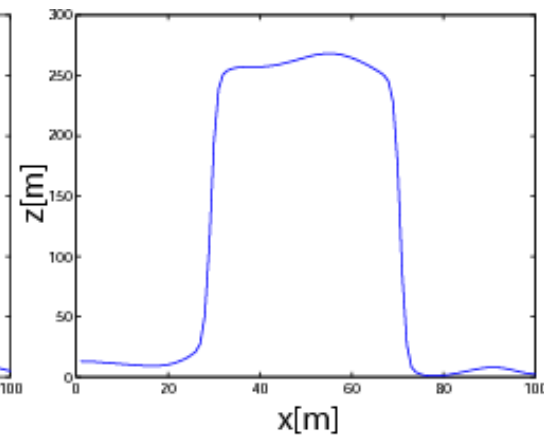
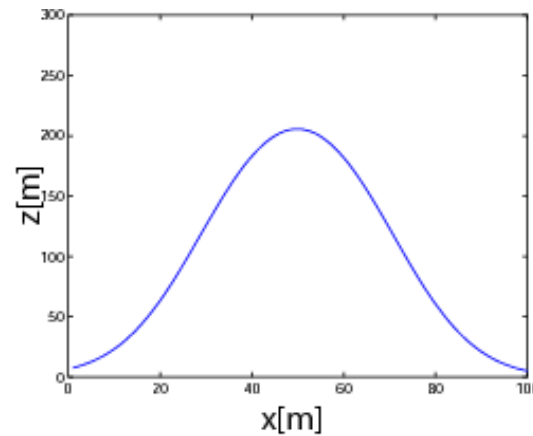
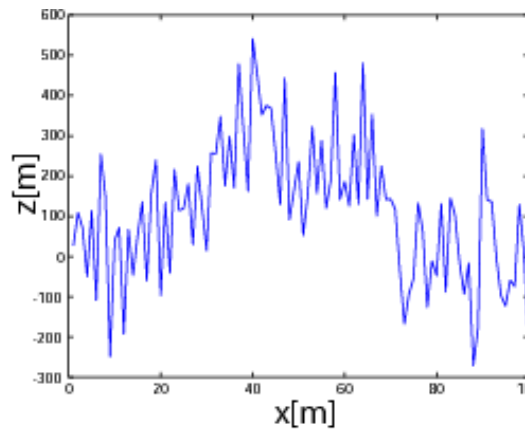
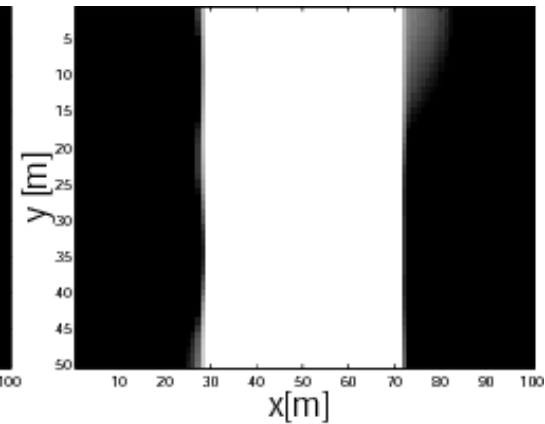
Original data with noise



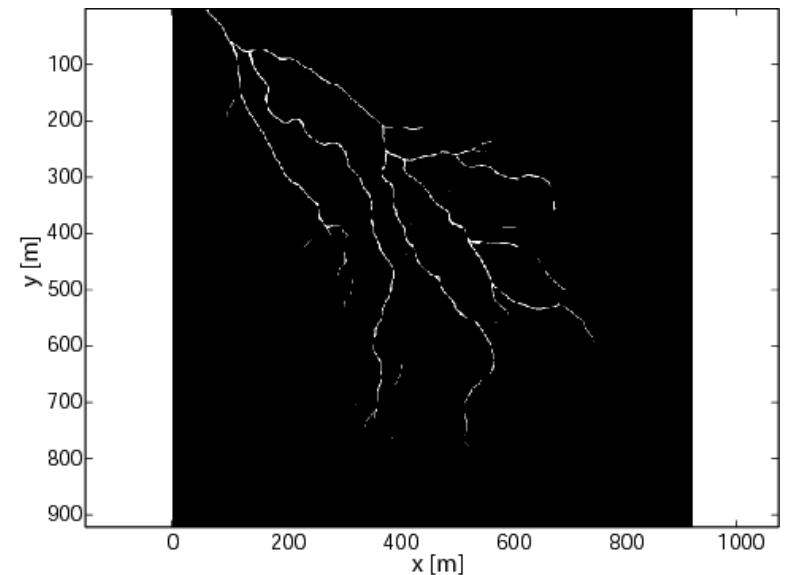
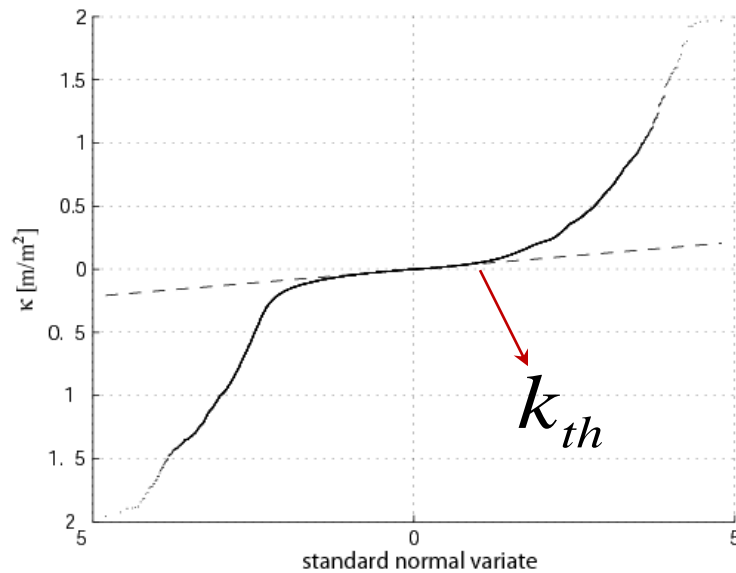
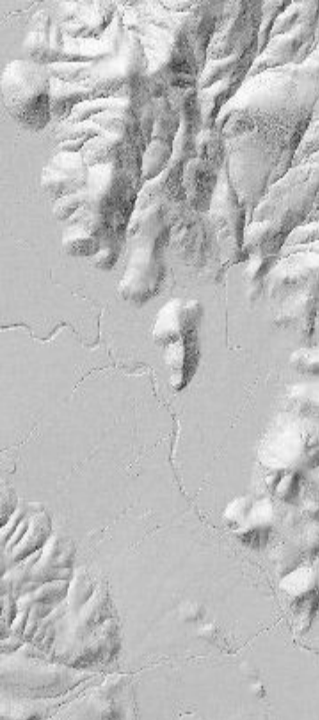
Gaussian filtering  $\sigma = 14$



Perona-Malik  $t = 200$



# 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.

## Extraction method

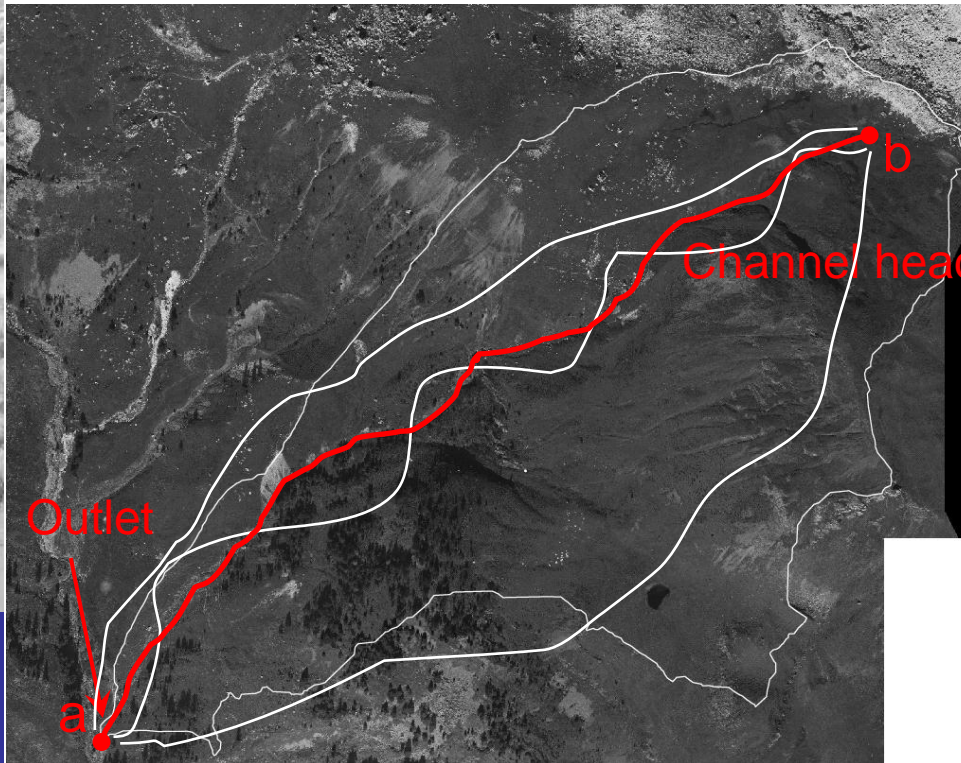
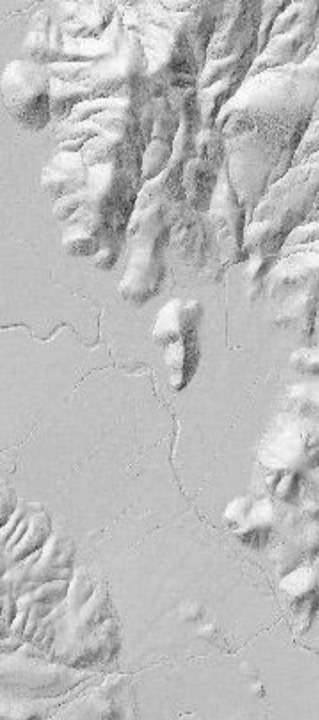
Linear vs.  
Skeleton  
Geodesics

Applications  
Channel initiation  
Channel disruptions  
Channel morphology  
Vegetation and climate

New release

Conclusions

# Channel extraction: geodesics



What makes the channel special?

## Extraction method

Linear vs.  
Skeleton  
Geodesics

## Applications

Channel initiation  
Channel disruptions  
Channel morphology  
Vegetation and climate

## New release

## Conclusions

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

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

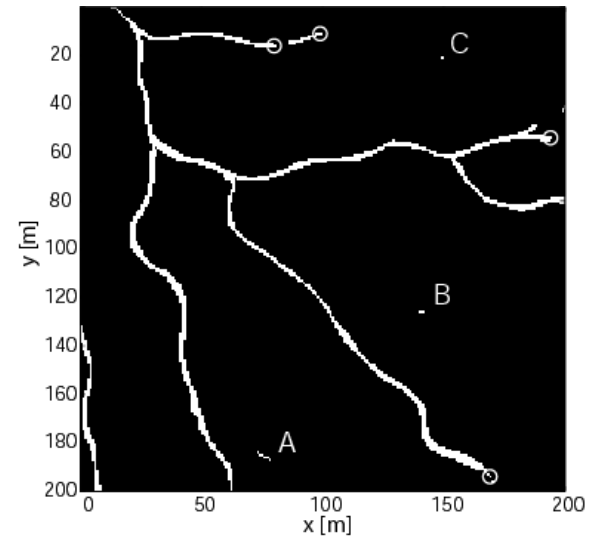
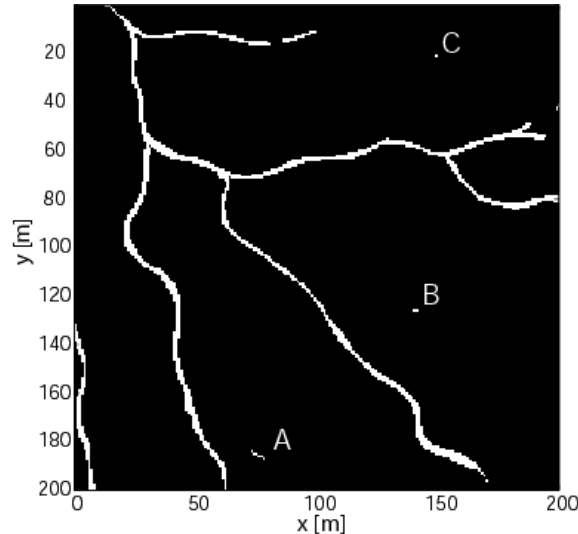
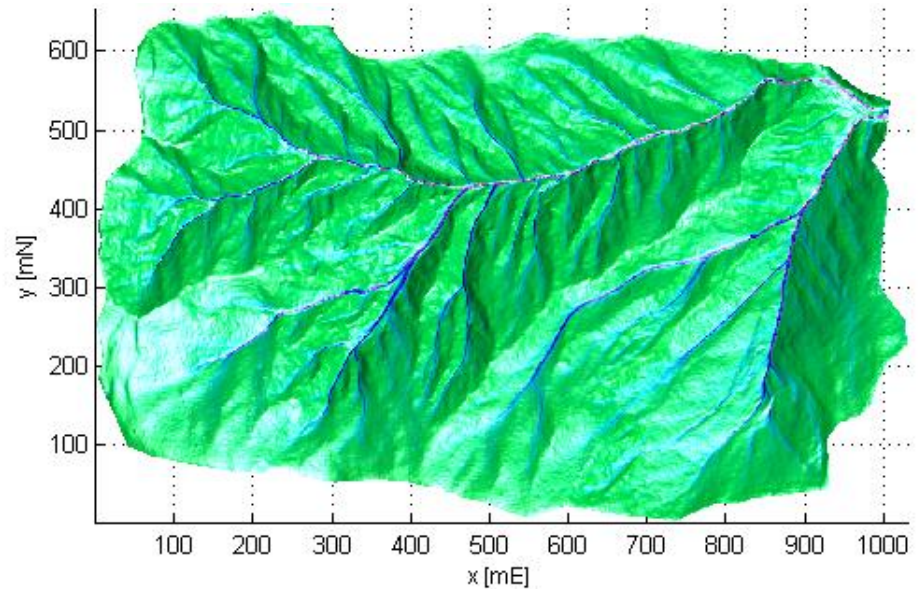
The curve with minimum cost is the geodesic curve:

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

# End point detection

The cost is minimum  
along the channels

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

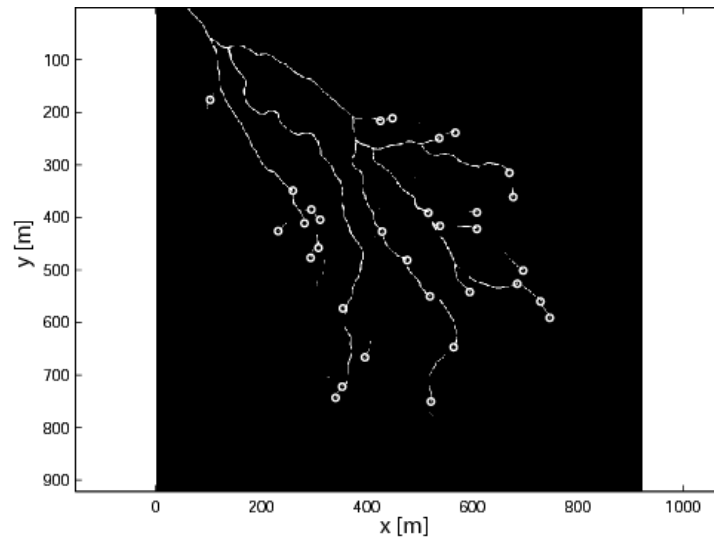


End points are identified as the points of the skeleton at minimum geodesic distance from the outlet.

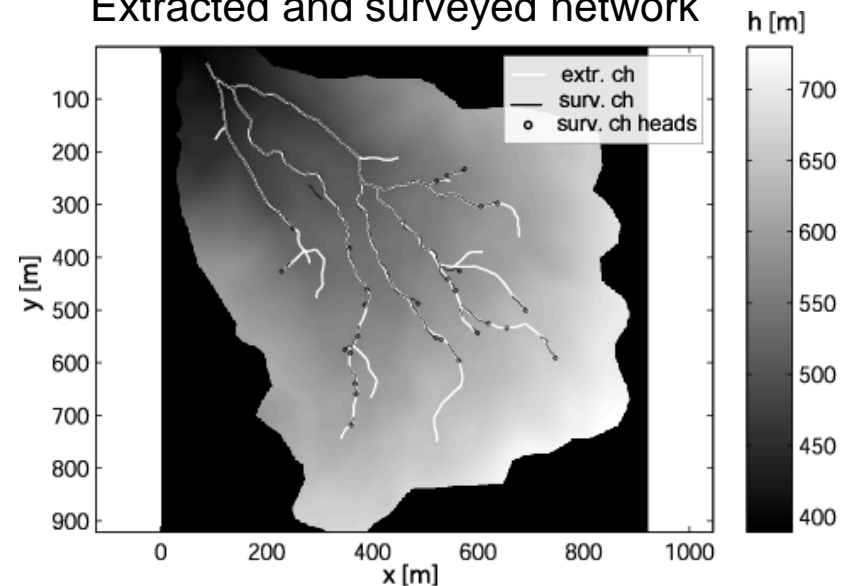


# Channel extraction

Skeleton with end points



Extracted and surveyed network



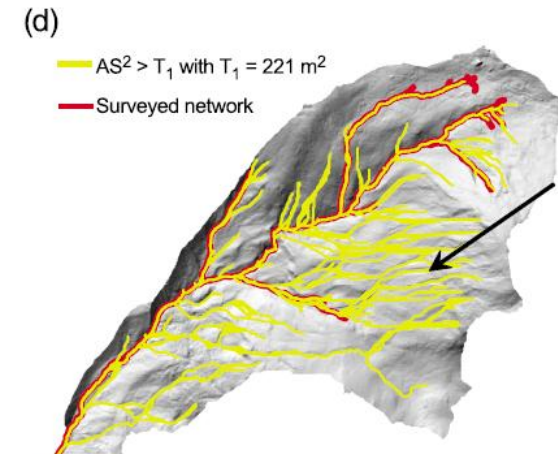
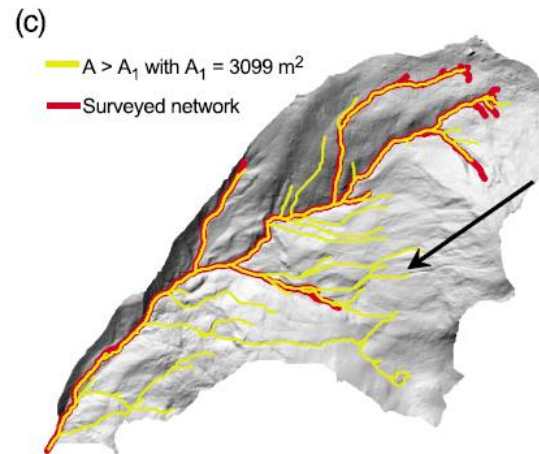
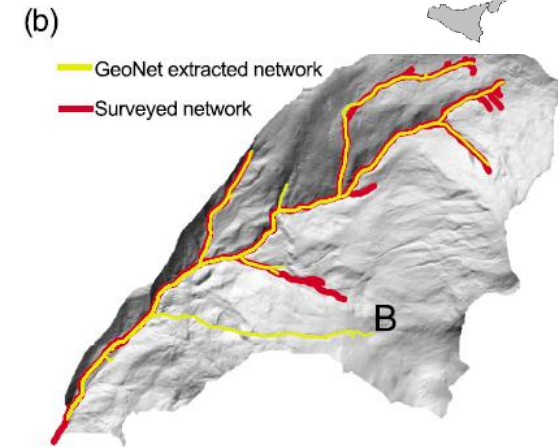
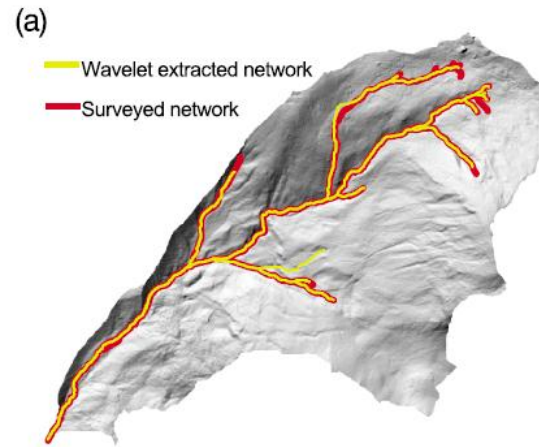
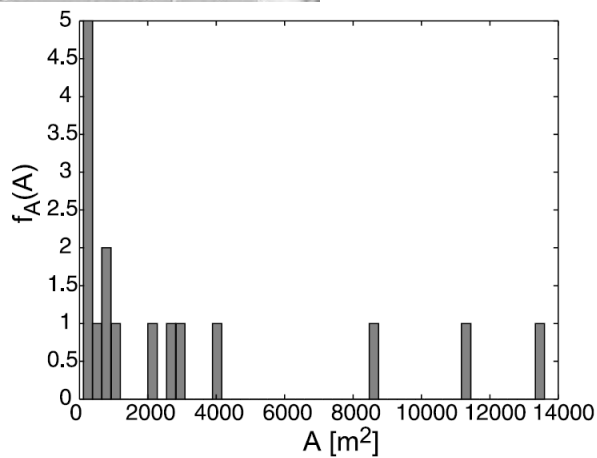
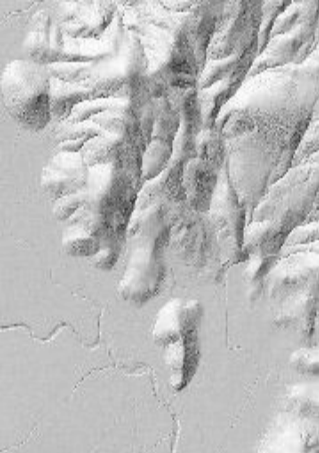
The curve with minimum cost is the geodesic curve:

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

Channels are traced by gradient descent on the geodesic distance.

# Applications: Channel initiation

With Paolo Tarolli, Efi Foufoula-Georgiou



0 75 150 300m



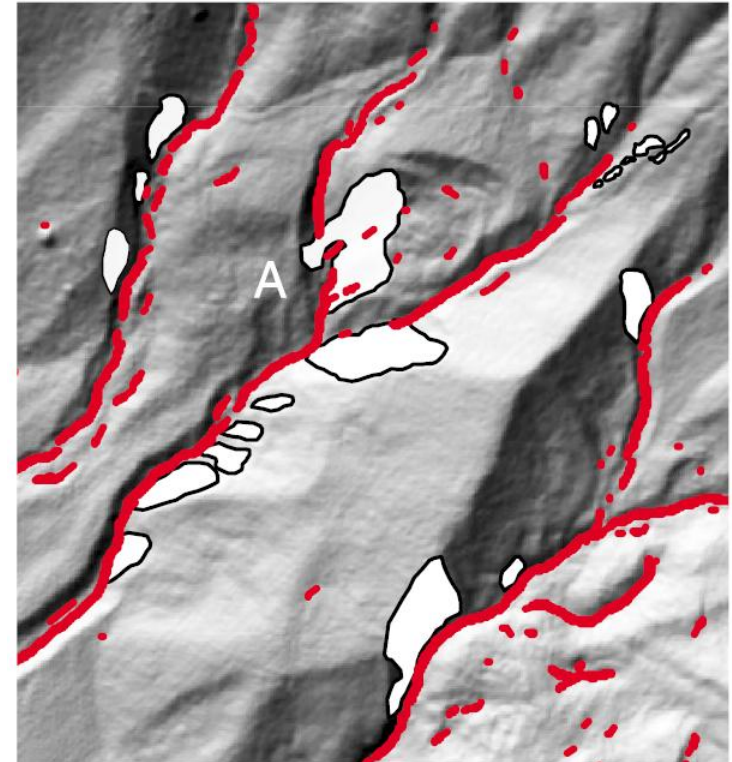
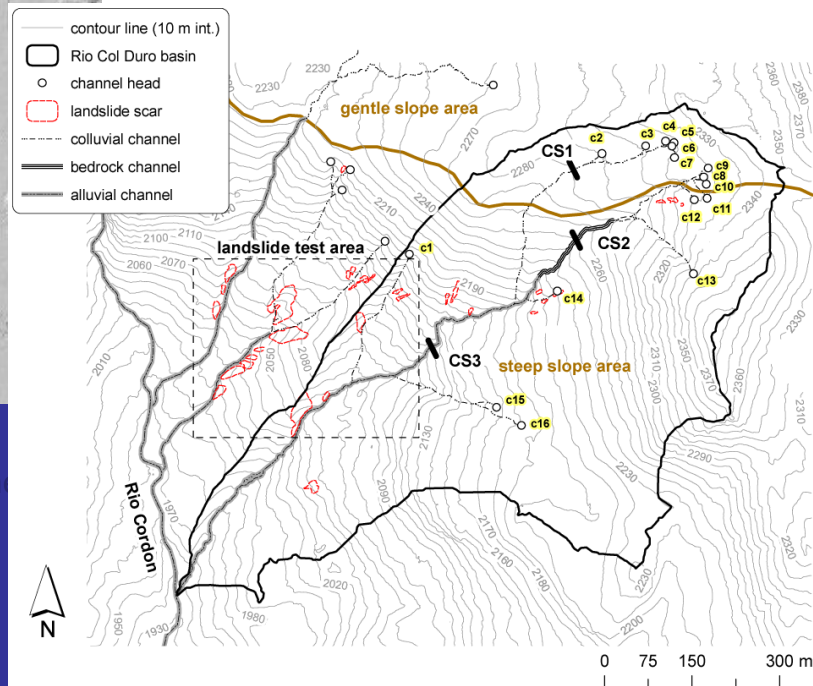
- Applications
  - Channel initiation
  - Channel disruptions
  - Channel morphology
  - Vegetation and climate

- New release

- Conclusions

# Applications: Channel disruptions

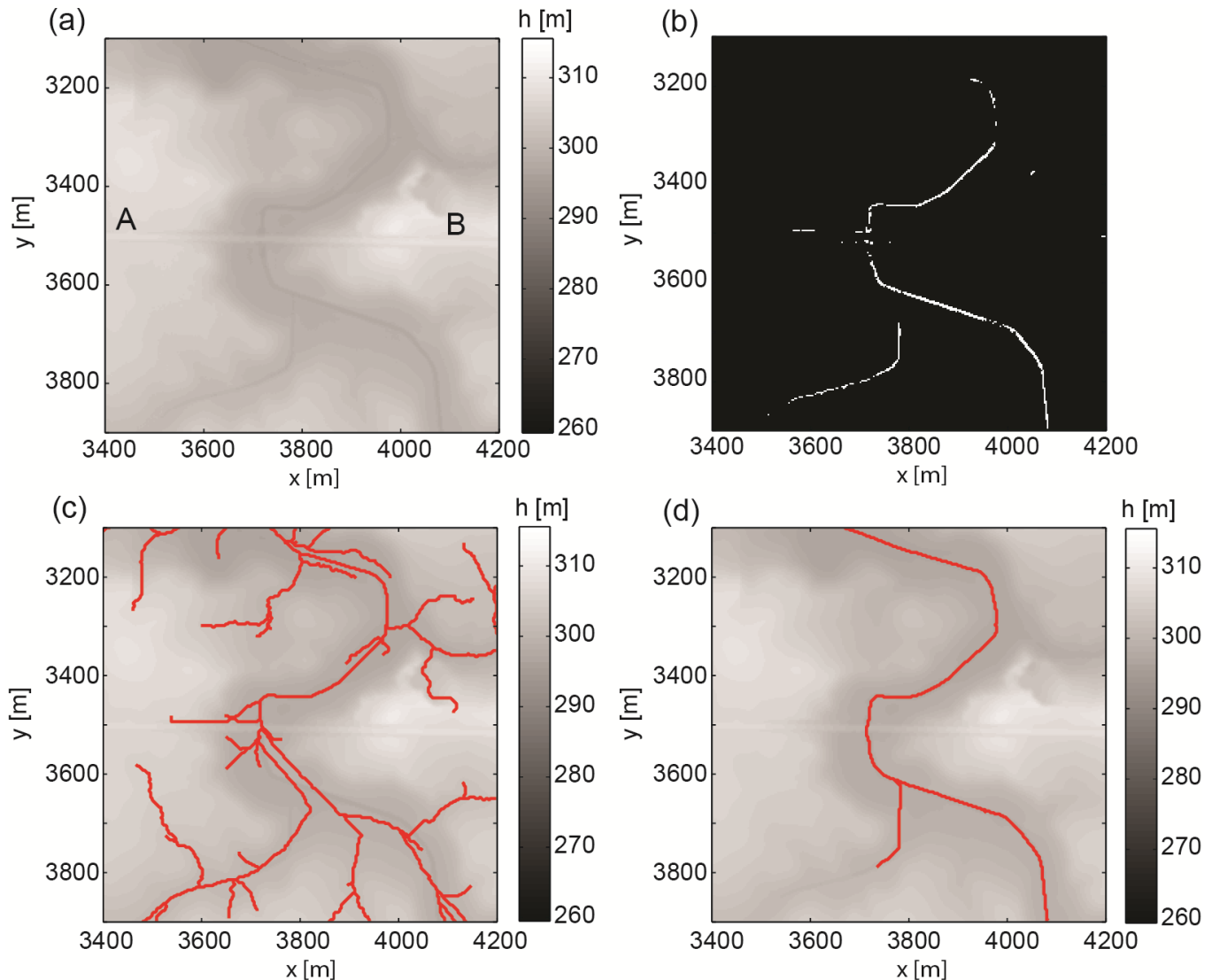
With Paolo Tarolli, Efi Foufoula-Georgiou



- Extraction methods  
Linear vs. Skeleton  
Geodesics
- Applications  
Channel initiation  
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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.

- Extraction method
  - Linear vs.
  - Skeleton
  - Geodesics

- Applications
  - Channel initiation
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  - Channel morphology
  - Vegetation and climate

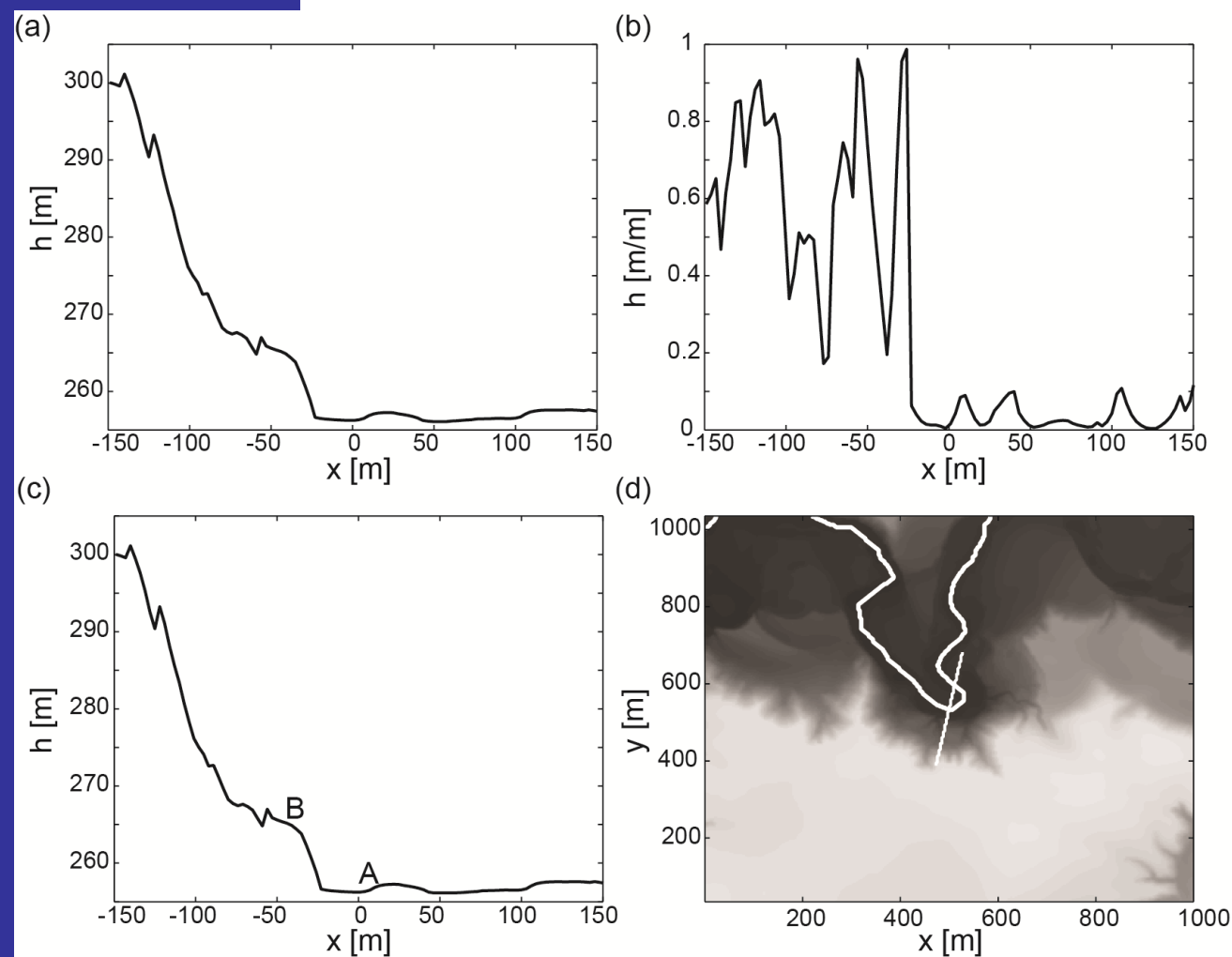
- New release

- Conclusions



# Applications: Flat lands and channel morphology

With Patrick Belmont, Efi Foufoula-Georgiou



Source: P. Belmont

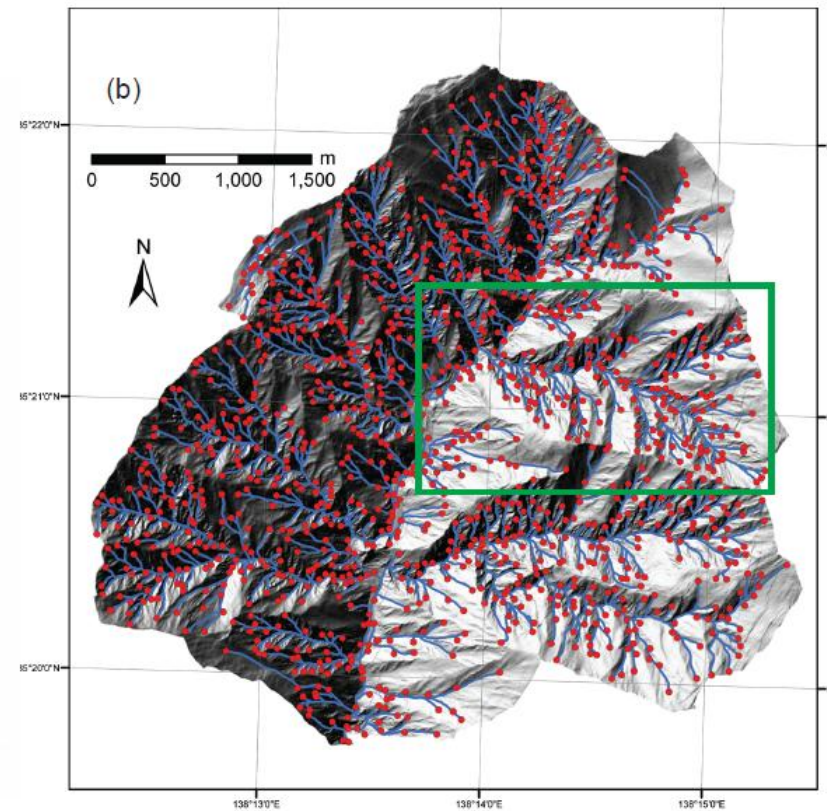
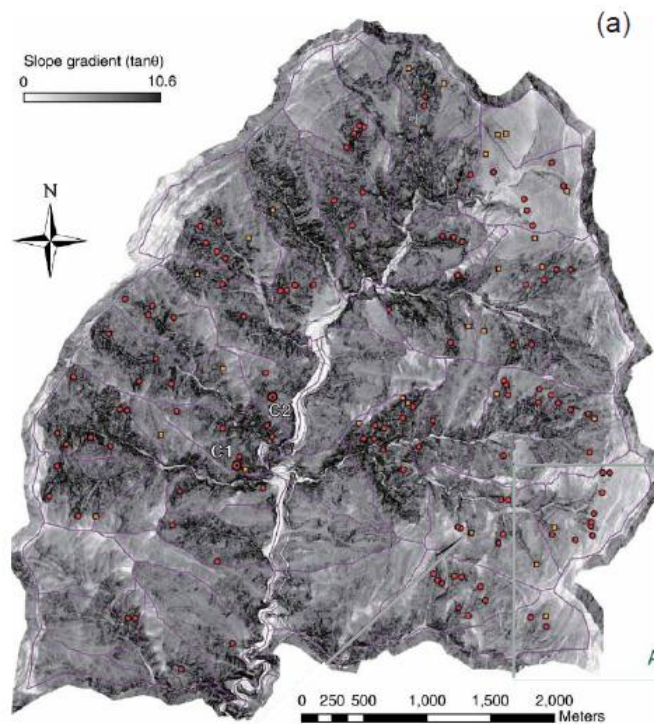


Source: C. Jennings



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

With Colin Stark, Harish Sangireddy



- Extraction method  
Linear vs.  
Skeleton  
Geodesics

- Applications  
Channel initiation  
Channel disruptions  
Channel morphology  
Vegetation and climate

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- Conclusions

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

With Colin Stark, Harish Sangireddy

(a)

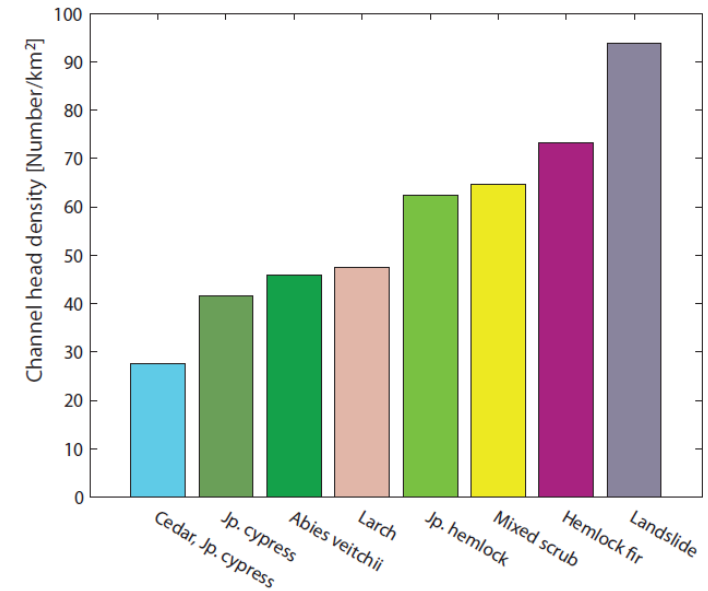
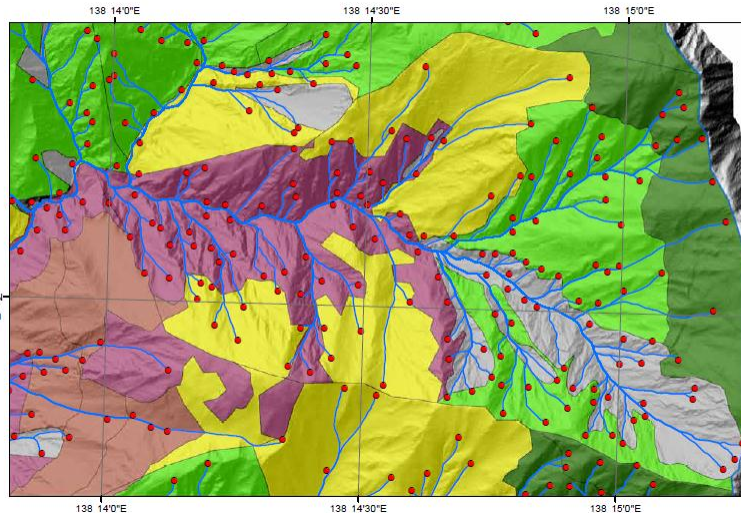


(b)

## Vegetation type

- Abies veitchii
- Acer, Hornbeam
- Birch
- Cedar
- Cedar, Japanese cypress
- Cunninghamia lanceolata
- Fagus crenata
- Fir
- Fraxinus spaethiana
- Hemlock fir
- Japanese cypress
- Japanese hemlock, Emman's Birch
- Larch
- Red pine
- Landslide
- Mixed scrub

0 100 200 300 400 500 m

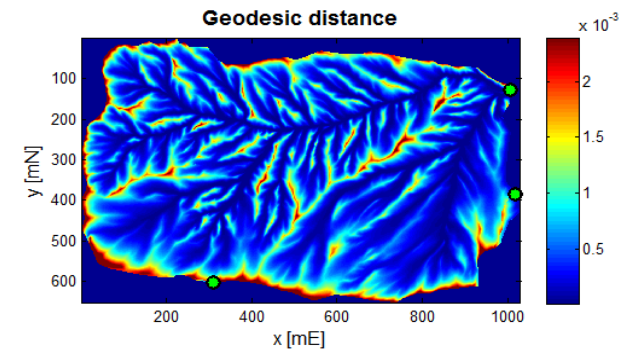
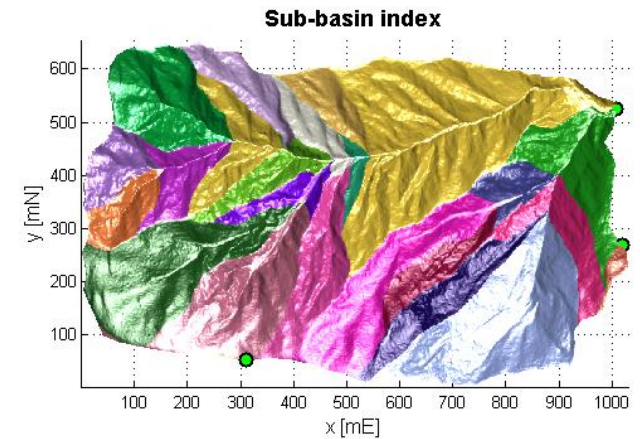




# GeoNet 2.0 – Release date Nov. 15 2011

With Colin Stark, Harish Sangireddy

- 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



■ Extraction method  
Linear vs.  
Skeleton  
Geodesics

■ Applications  
Channel initiation  
Channel disruptions  
Channel morphology  
Vegetation and climate

■ New release

■ Conclusions

# GeoNet 2.0 – Release date Nov. 15 2011

With Colin Stark, Harish Sangireddy

Website at [sites.google.com/site/geonethome/](http://sites.google.com/site/geonethome/)

(online at release date)

## GeoNet - lidar DTM analysis

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Lamont-Doherty Earth Observatory
National Center for Earth-surface Dynamics
National Center for Airborne Laser Mapping
NSF Geography and Spatial Sciences
NSF Geomorphology and Land-use Dynamics
Open Topography
Matlab documentation
Contacts
Paola Passalacqua
Harish Sangireddy
Colin Stark

### What is GeoNet?

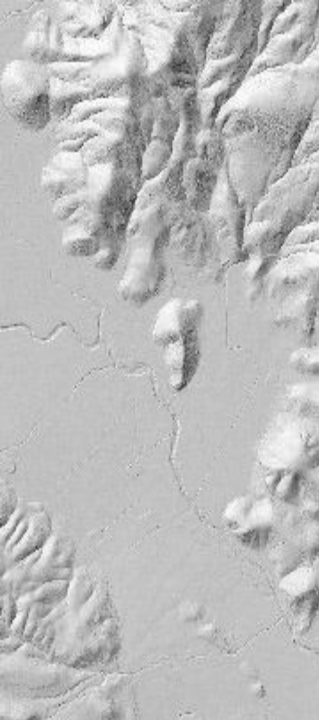
Coming soon!

### Installation

1. General  
Geonet is a Matlab toolbox.
2. MS-Windows  
Install Matlab on windows and follow the steps below:
3. Mac OS-X  
Install Matlab on Mac OS-X and follow the steps below
4. Linux  
Install Matlab on Linux and follow the steps below:

### Documentation

- ▀ [Geonet Terminology](#)
- ▀ [Basic Matlab Concepts](#)
- ▀ [Five minute Program Launch Tutorial](#) ( probably



- ▀ Extraction method  
Linear vs.  
Skeleton  
Geodesics
- ▀ Applications  
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Vegetation and climate
- ▀ New release
- ▀ Conclusions

# 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.

Work supported by:

NSF EAR-0835789 (Pis Foufoula-Georgiou and Sapiro)

NCED (NSF EAR-0120914)

NSF BCS-1063231/1063228 (PIs Stark and Passalacqua)

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