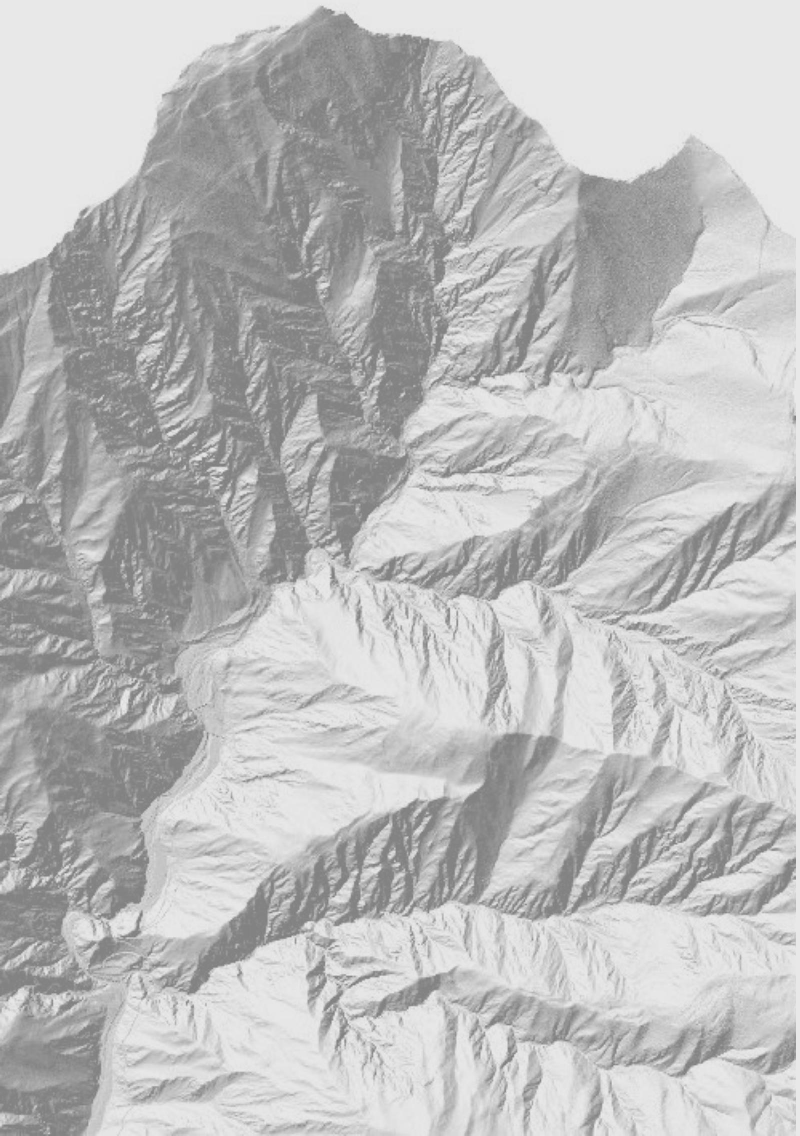
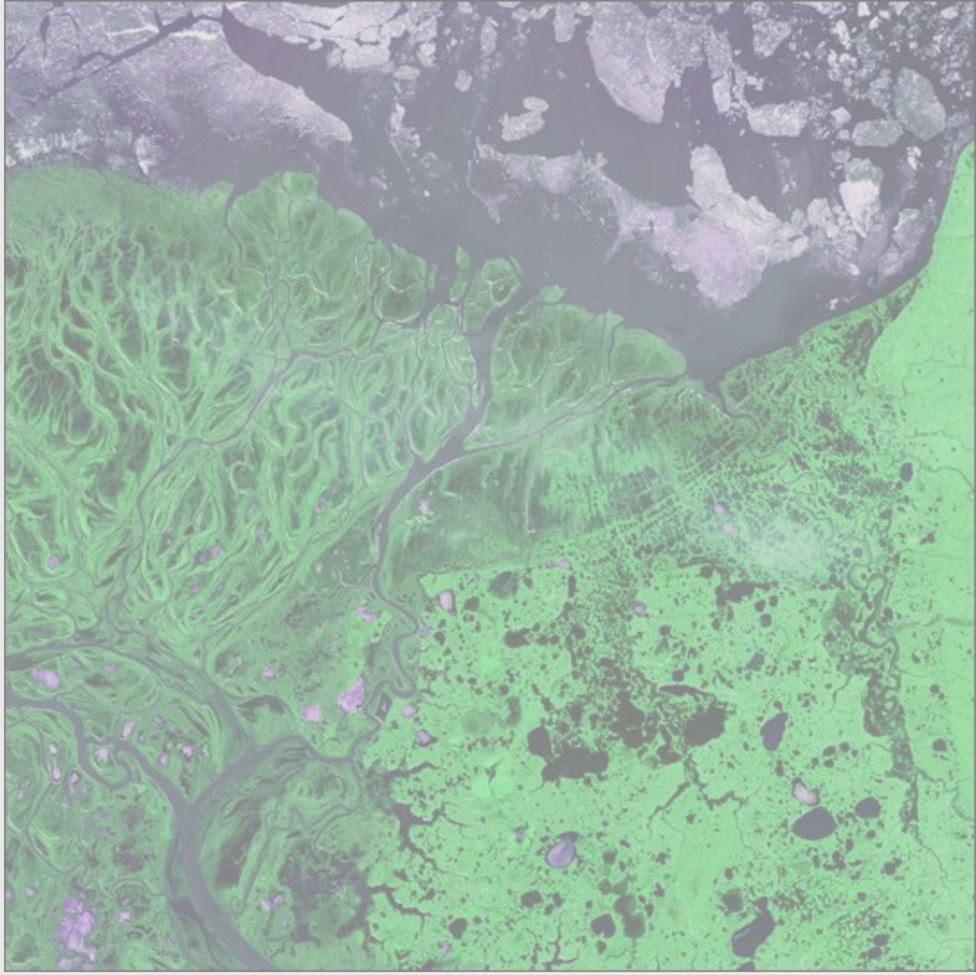
Channel network structure and transport dynamics





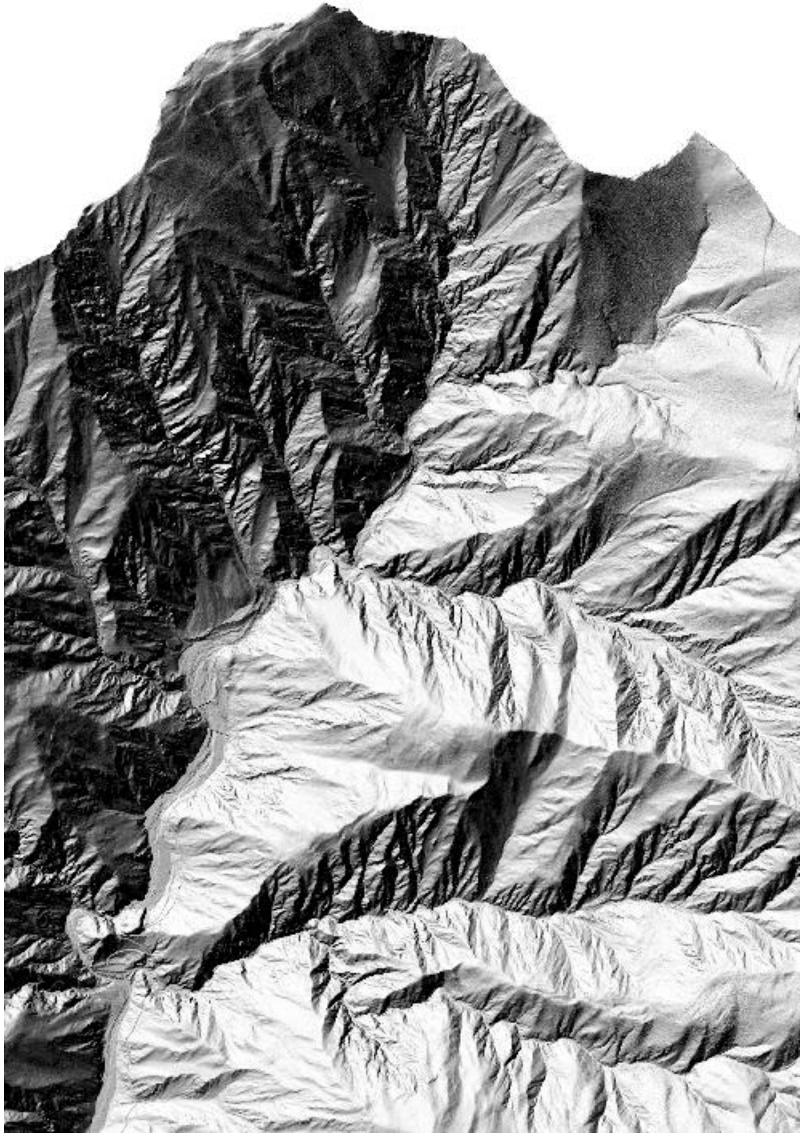
Paola Passalacqua

Matt Hiatt, Harish Sangireddy,
Man Liang, and Nathanael Geleynse

Dept. of Civil, Architectural, and Environmental Engineering
UT Austin

394K.3 Guest lecture, 07 November 2013

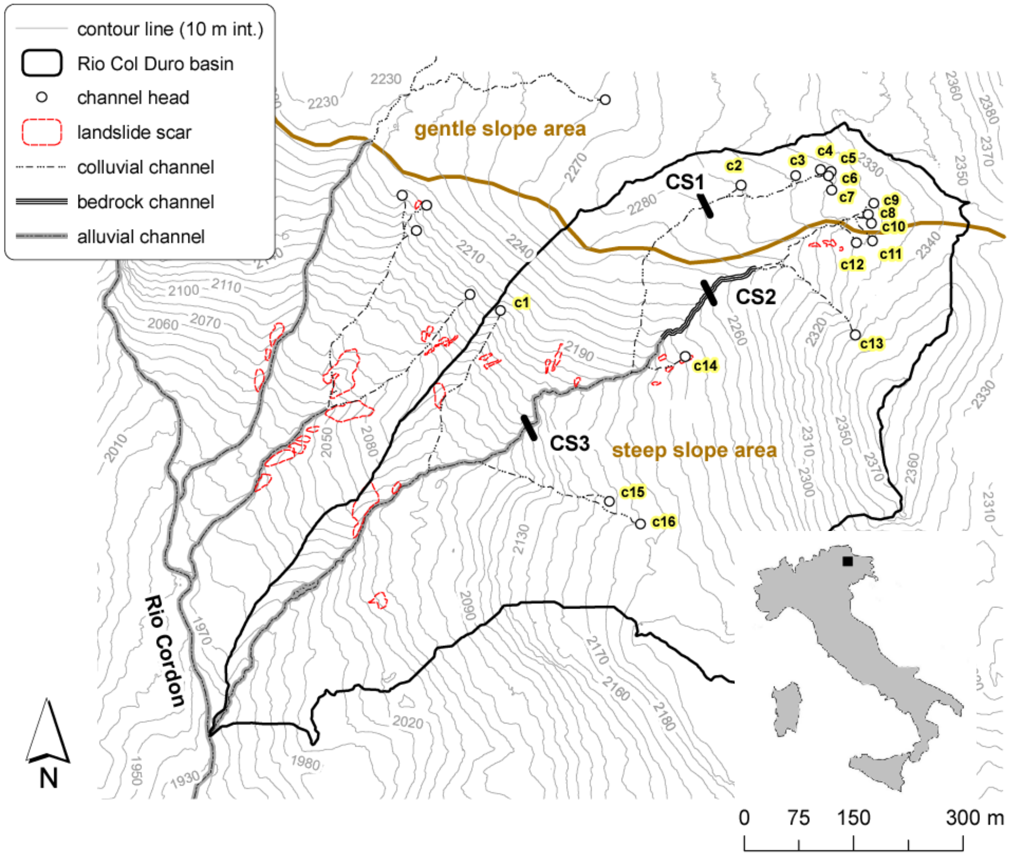
Digital landscapes



Topographic patterns can be resolved over large areas at resolutions commensurate with the scale of governing processes

Ikawa experimental watershed, Japan

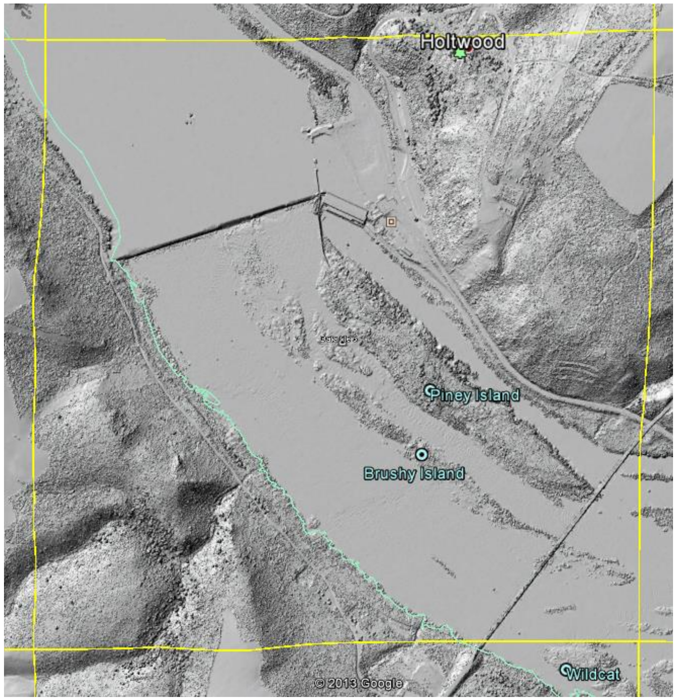
Variability of contributing area at channel heads

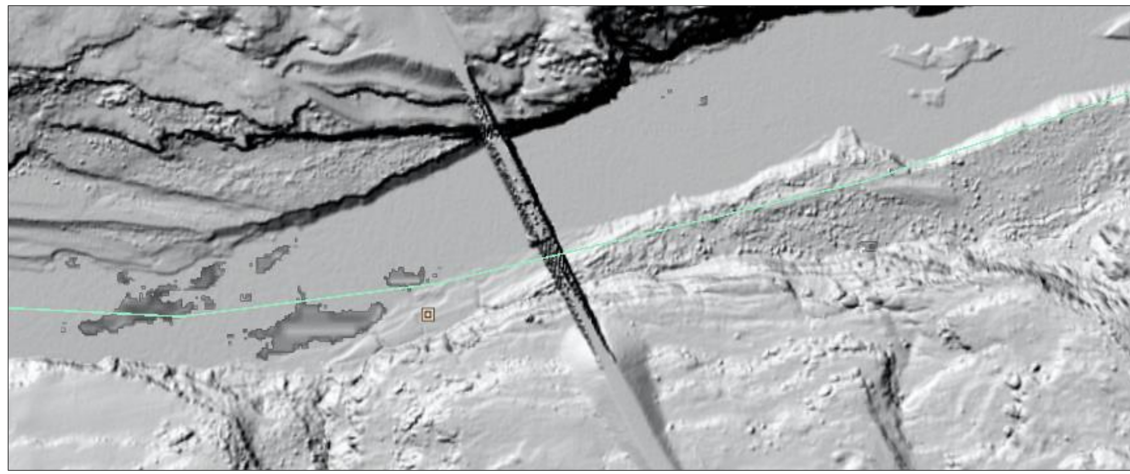


- Opportunity to characterize variability in drainage area at channel heads
- Challenge for classic extraction methods

Cordon River basin, Italy

Natural versus man-made features



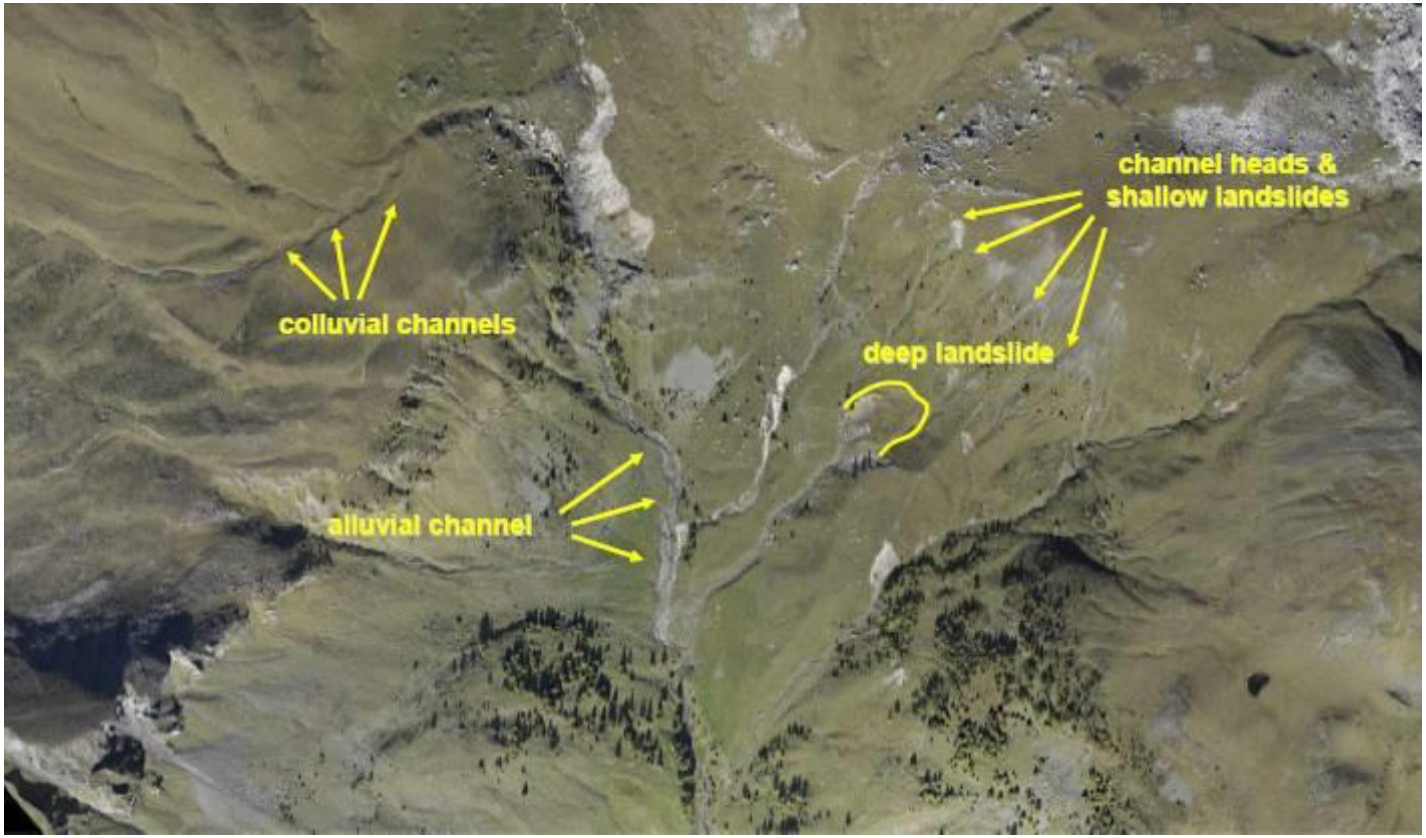


- Engineered features interfere with channel extraction process
- Challenge for classic extraction methods based on steepest descent

Susquehanna River, PA

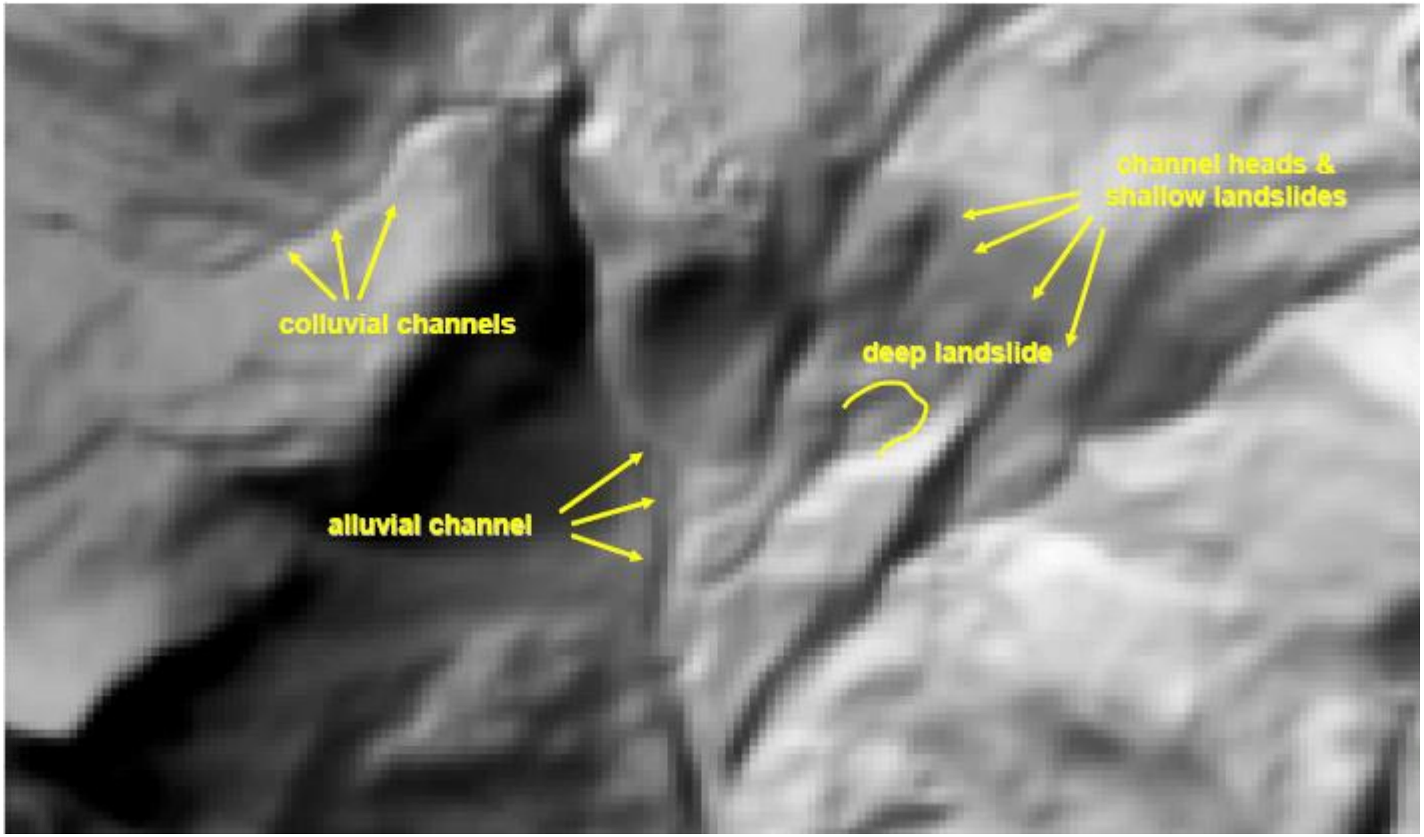
The importance of data resolution

Rio Cordon basin, Selva di Cadore, Italy



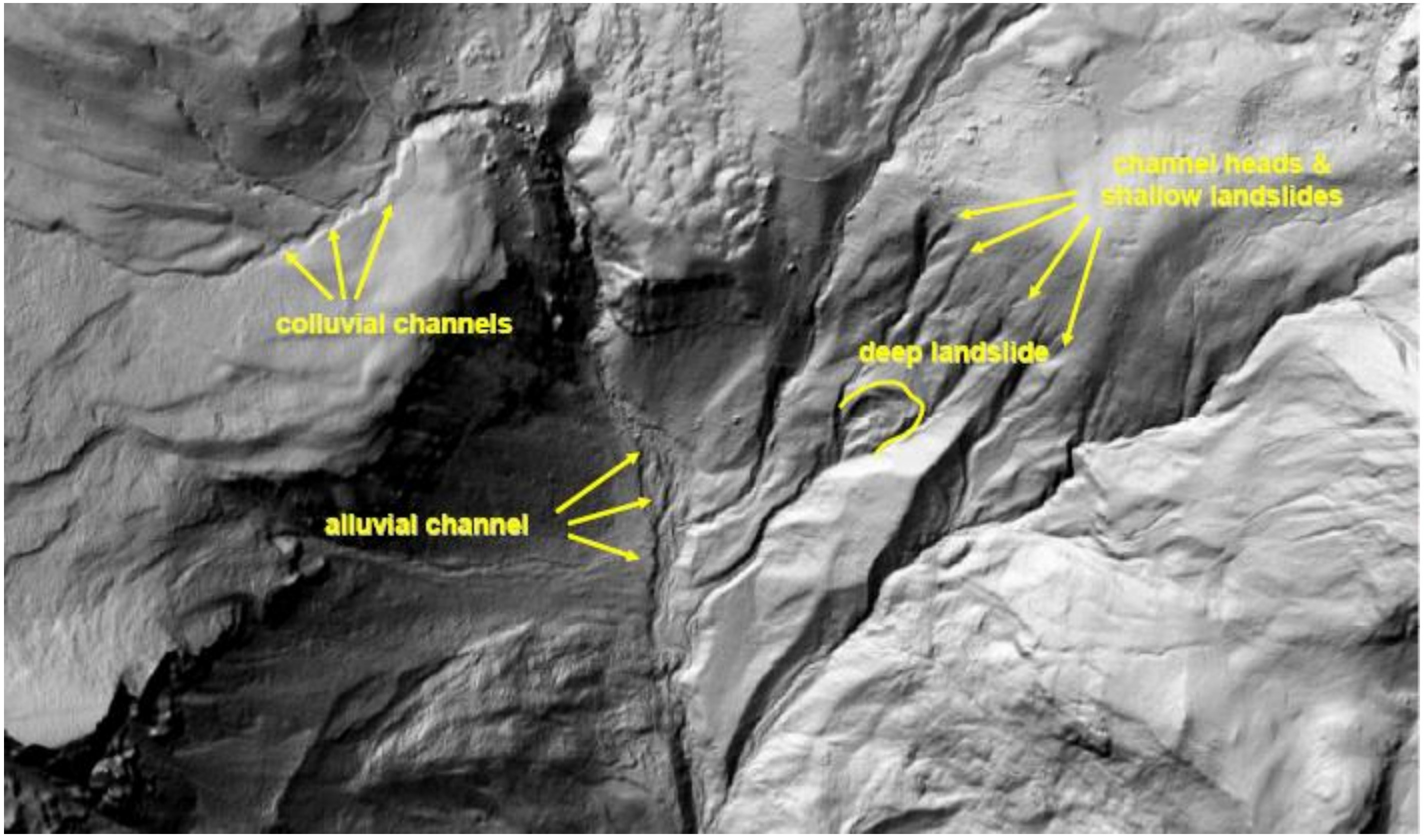
Slide courtesy of Dr. Paolo Tarolli, University of Padova, Italy

DTM 10x10 m



Slide courtesy of Dr. Paolo Tarolli, University of Padova, Italy

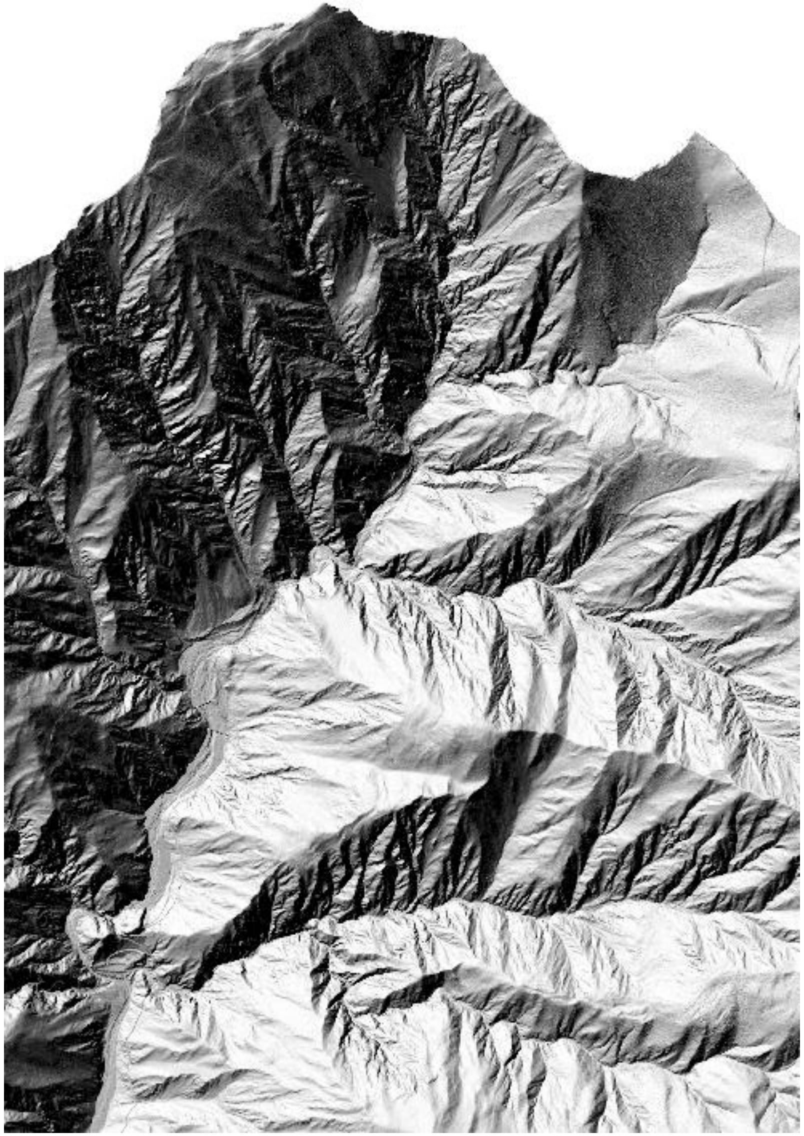
DTM 1x1 m



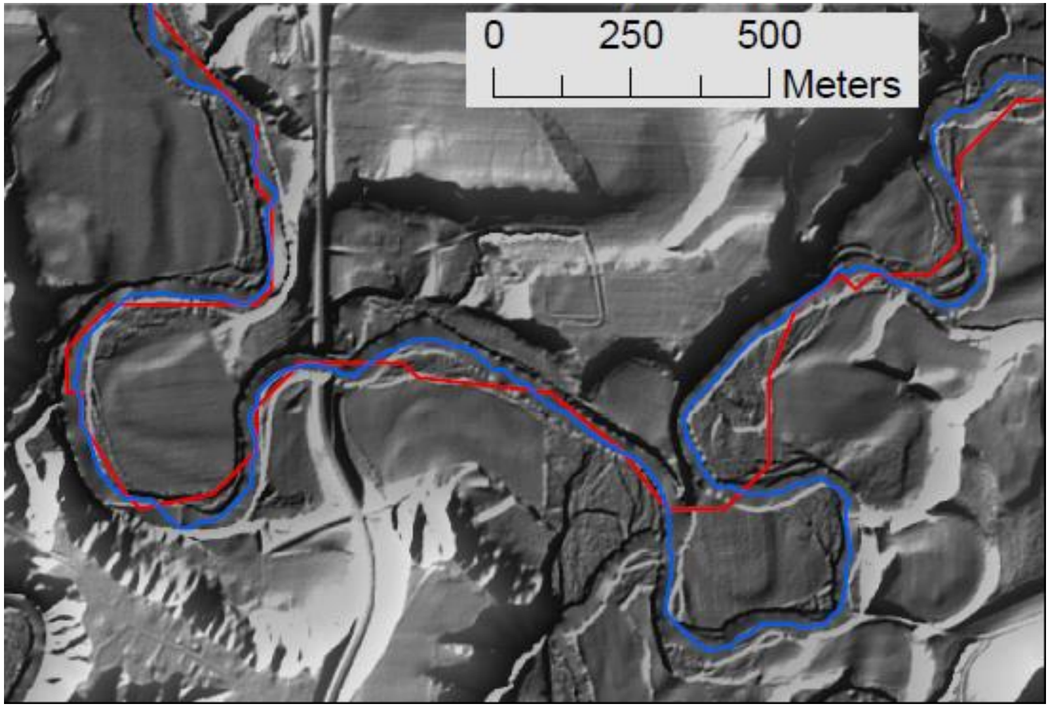
Slide courtesy of Dr. Paolo Tarolli, University of Padova, Italy

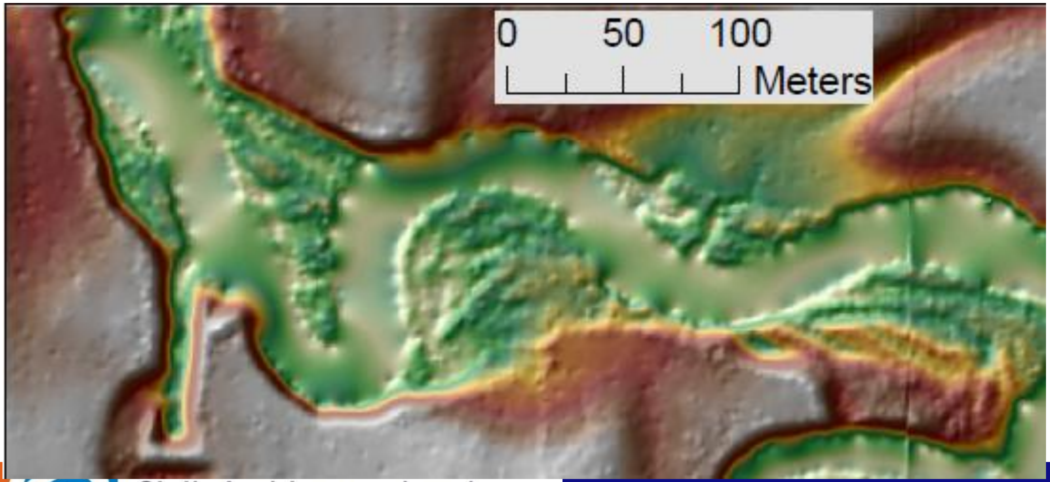
Lidar DTMs: Solving the resolution problem?

- Availability of meter and sub-meter resolution topographic data
- Topographic patterns can be resolved over large areas at resolutions commensurate with the scale of governing processes
- Importance of objective extraction of geomorphic feature



Challenges in geomorphic feature extraction





- Channel initiation
- Identification of accurate centerline
- Presence of roads and bridges
- Artificial drainage ditches
- Small signal to noise ratio
- Identification of channel banks

GeoNet: An open-source toolbox for channel extraction

- **Home**
  - Acknowledgments
  - Contributors
- Data
- Documentation
  - Code structure
  - FAQ
  - Matlab concepts
  - Revision history
  - Test cases
- Download
- How-to
- License
- Publications
  - Conference presentations
  - Journal articles
- Sitemap

Links

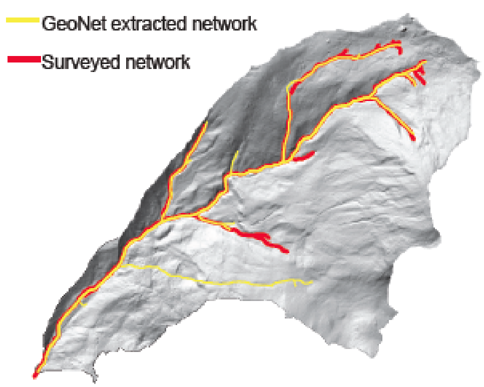
- UT Austin CAEE
- L-DEO
- Open Topo
- NCALM
- NCED
- NSF-GSS

Home

Welcome to GeoNet 2.0

GeoNet 2.0 is a MatLab-based computational tool for the automatic extraction of channel networks and geomorphic features from lidar data. It is the newest version of GeoNet, following GeoNet 1.0 and GeoNet 1.0.1. GeoNet 2.0 has been sustantially re-coded, but the basic idea behind the tool remains the same.

GeoNet combines nonlinear filtering for data preprocessing and cost minimization principles for feature extraction. The use of nonlinear filtering achieves noise removal in low gradient areas and edge enhancement in high gradient areas, i.e., near feature boundaries. After preprocessing, GeoNet extracts channels as geodesics—lines that minimize a cost function based on fundamental geomorphic characteristics of channels such as flow accumulation and curvature.

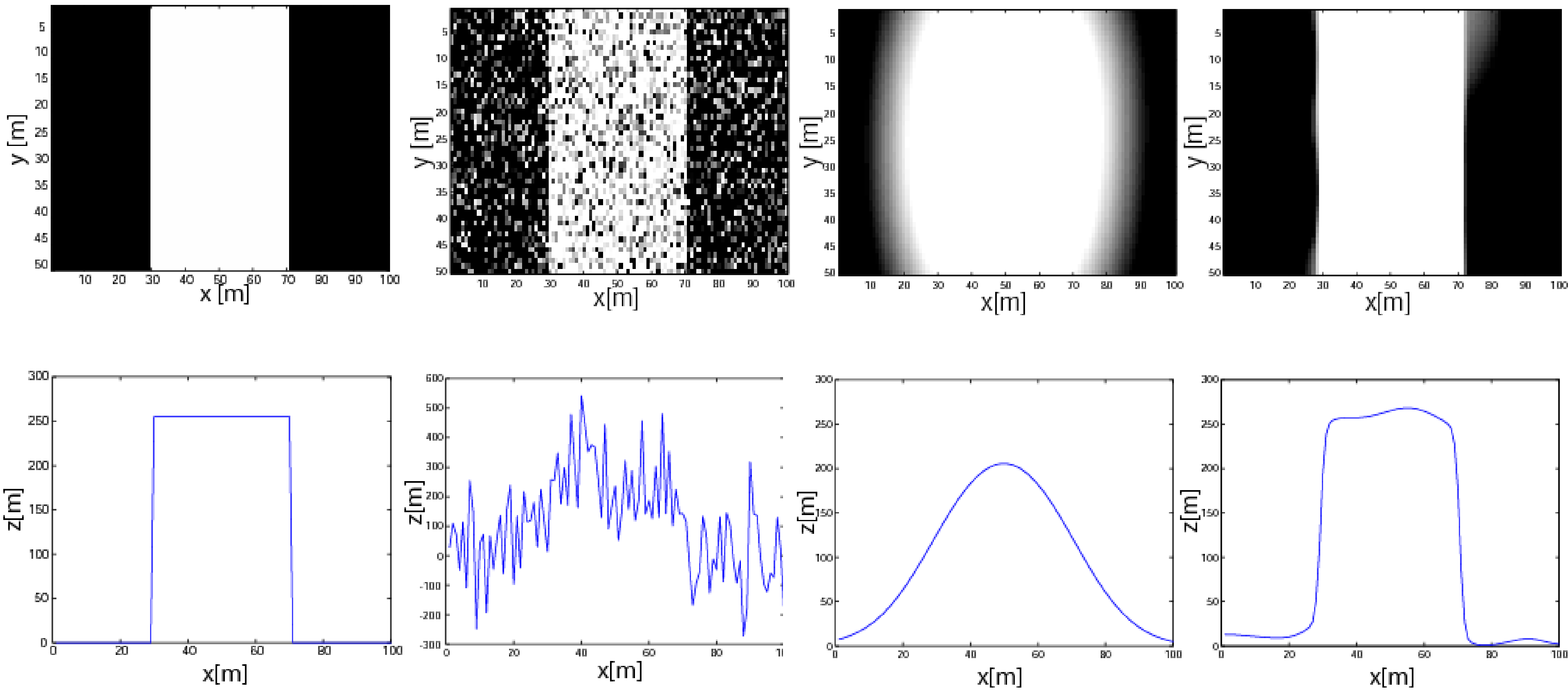


- Nonlinear filtering to remove small scale variability and enhance features of interest
- Statistical analysis of curvature to extract likely channelized pixels
- Geodesic minimization principles to extract channels

Nonlinear filtering

Enhance features of interest, while smoothing small scale features. Perona and Malik [1990]

$$\partial_t h(x,y,t) = \nabla \cdot \left(c(x,y,t)\nabla h\right) \qquad c = \frac{1}{1+\left(|\nabla h|/\lambda\right)^2}$$



Passalacqua, P., T. Do Trung, E. Foufoula-Georgiou, G. Sapiro, and W. E. Dietrich, J. Geophys. Res., 2010

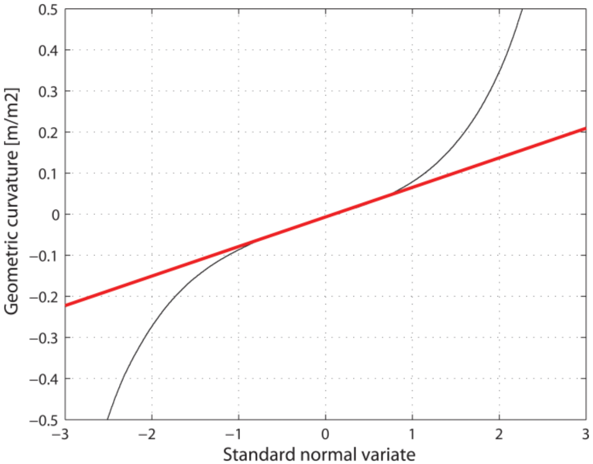
Nonlinear filtering

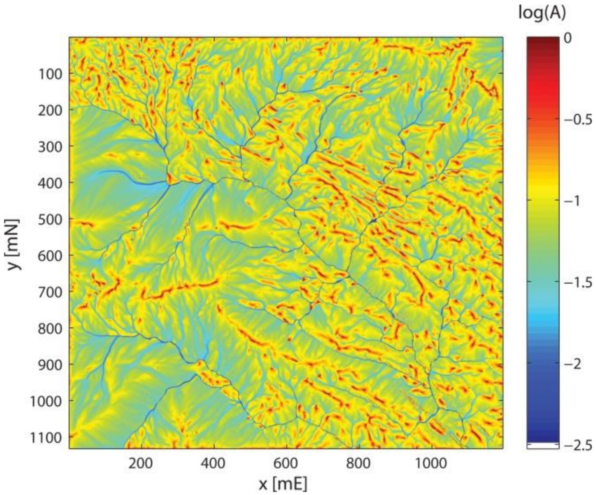
$$\partial_t h(x,y,t) = \nabla \cdot \left(c(x,y,t)\nabla h\right) \qquad c = \frac{1}{1+\left(|\nabla h|/\lambda\right)^2}$$

- Nonlinear diffusion with diffusion coefficient function of local gradient
- Preserves localization of features
- Removes small-scale variability (noise)
- Enhances features of interest (e.g., channel banks)
- Draw-back: challenged by noise of size comparable to features. Other filters to be explored.

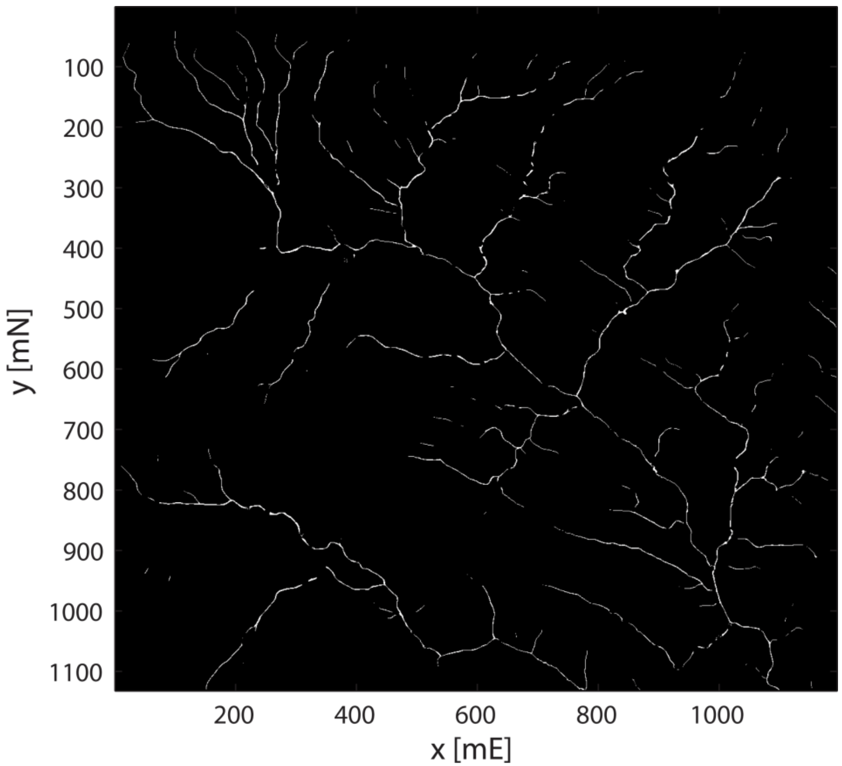
Statistical analysis of curvature

Curvature distribution deviation from Normal behavior interpreted as transition hillslope to valley [Lashermes et al.,2007]



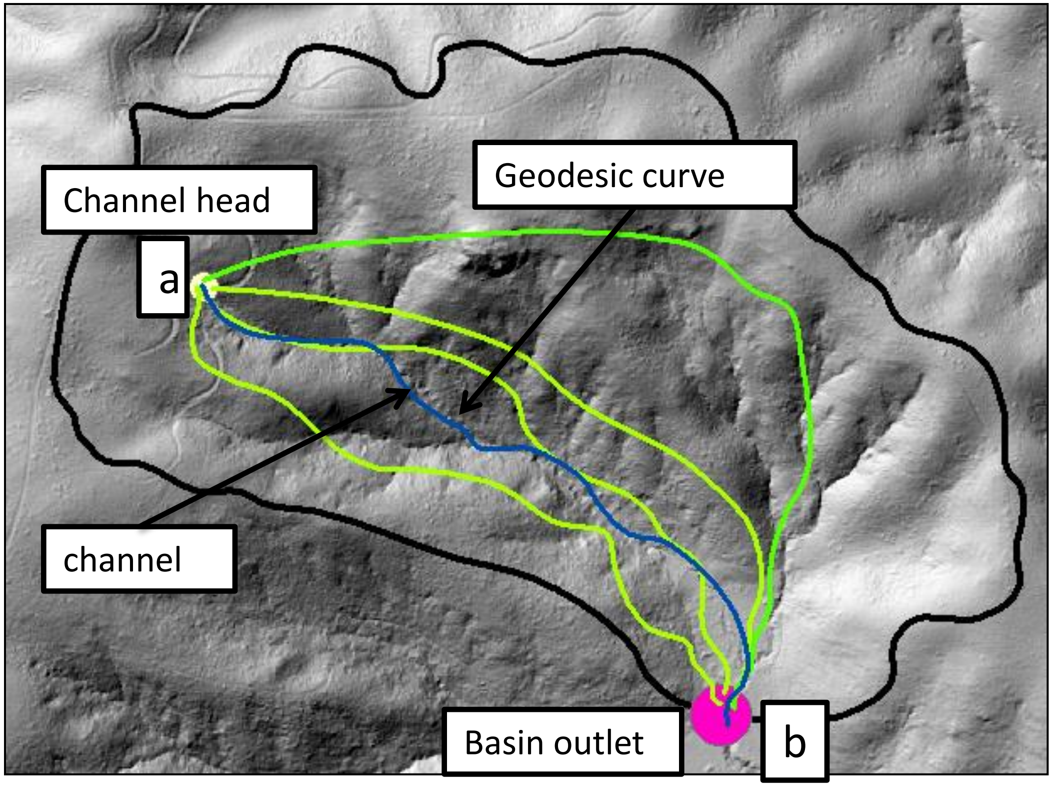


Skeleton of likely channelized pixels



Henry Mountains, UT

Geodesic minimization principles

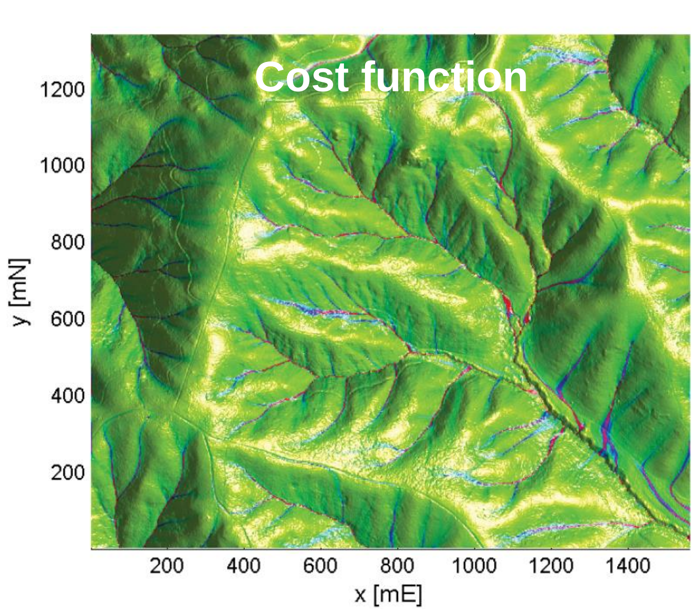


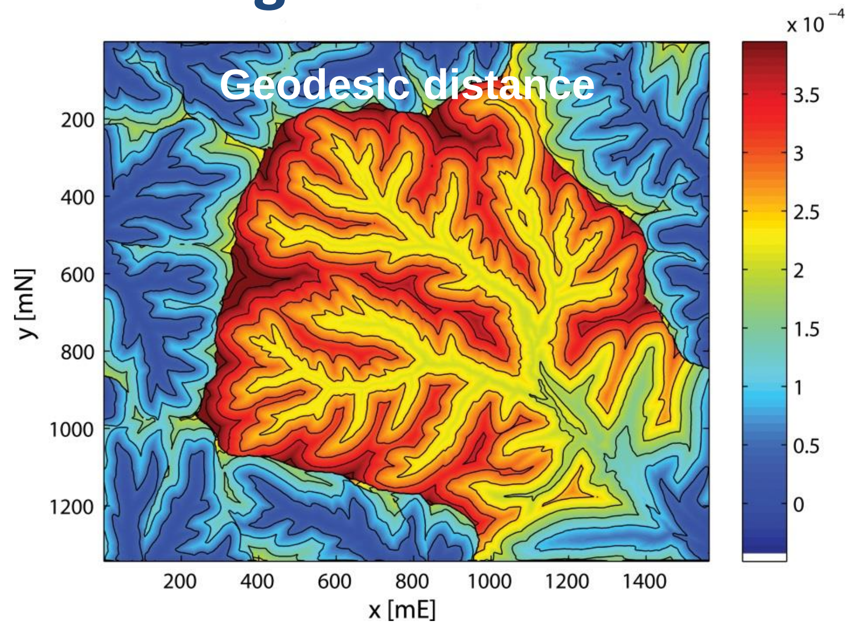
$$\psi = \frac{1}{\alpha A + \delta k}$$

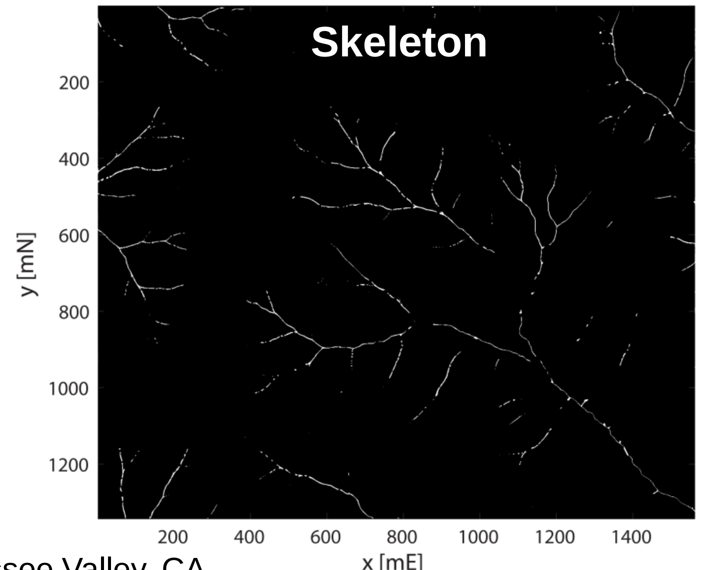
$$g(a,b) := \arg\left(\min_{C \in \Omega} \int_a^b \Psi(s)\, ds \right)$$

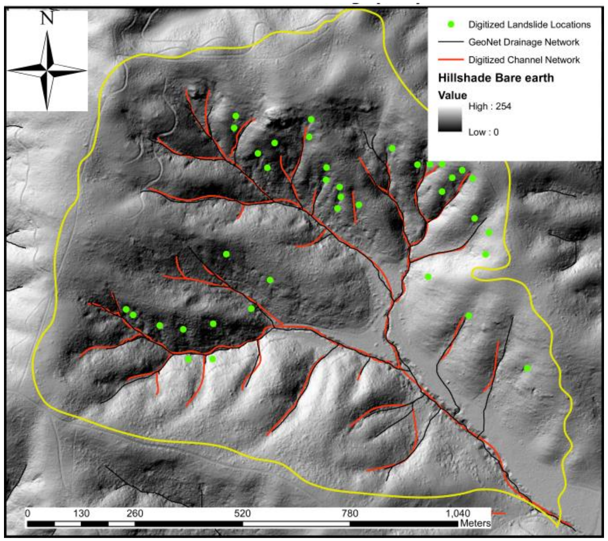
The *cost function* ψ represents the cost of traveling between point a and point b in terms of, e.g., surface curvature and flow accumulation.

Channels extracted as geodesics



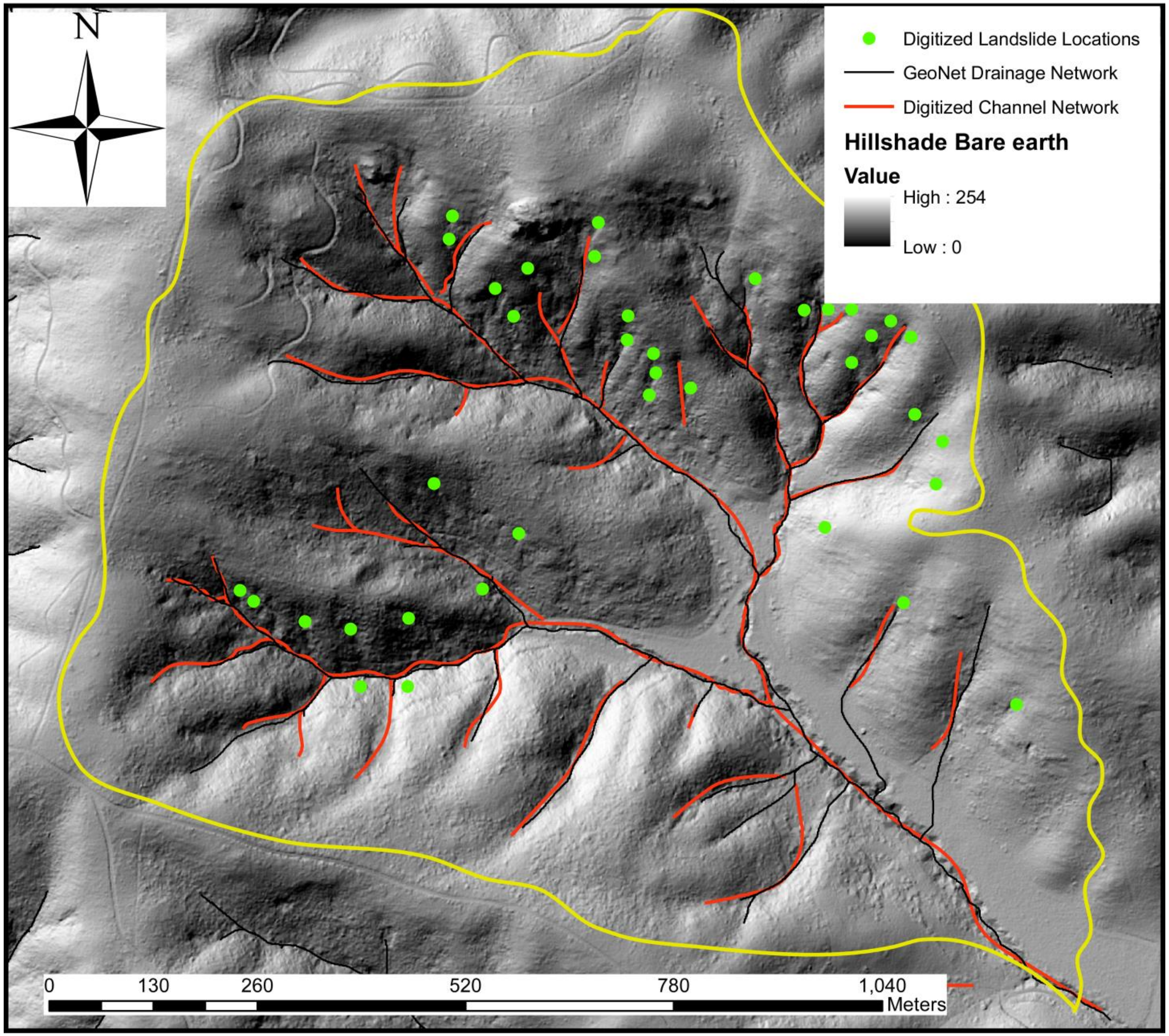






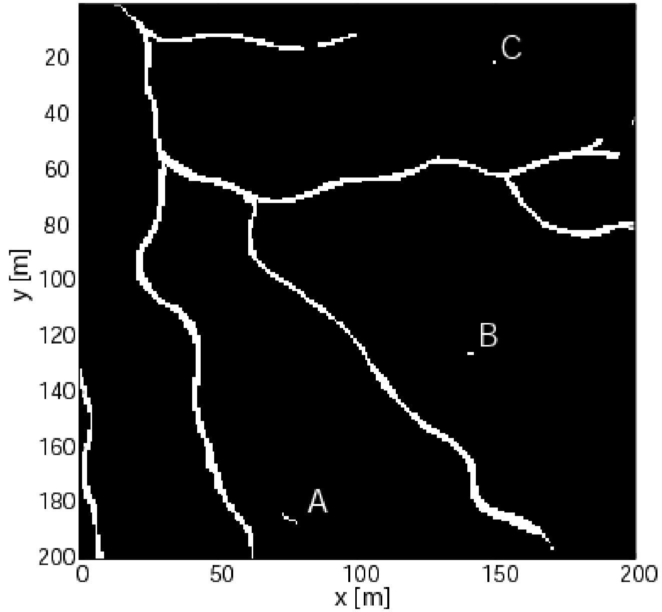
Tennessee Valley, CA

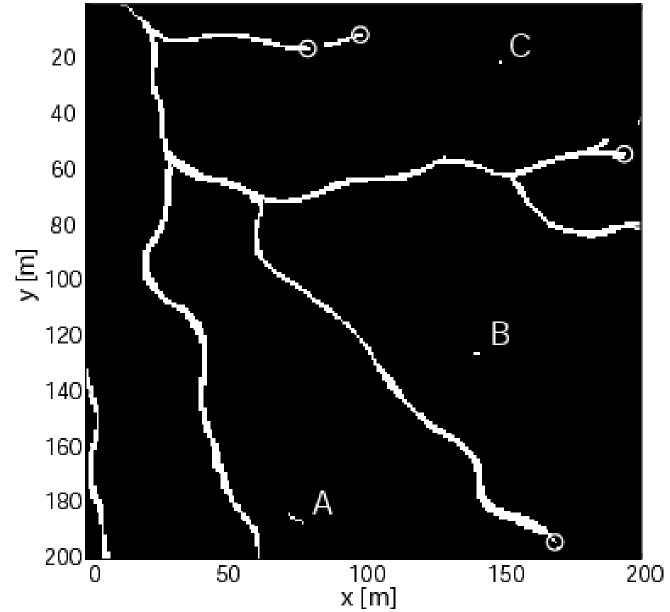
Extracted channel network compared to field data

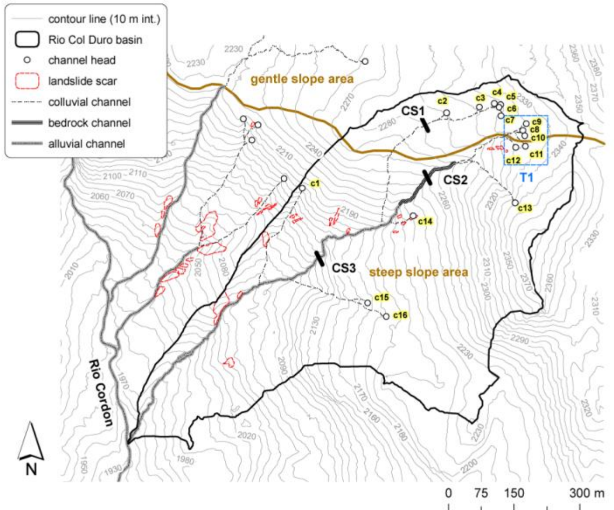


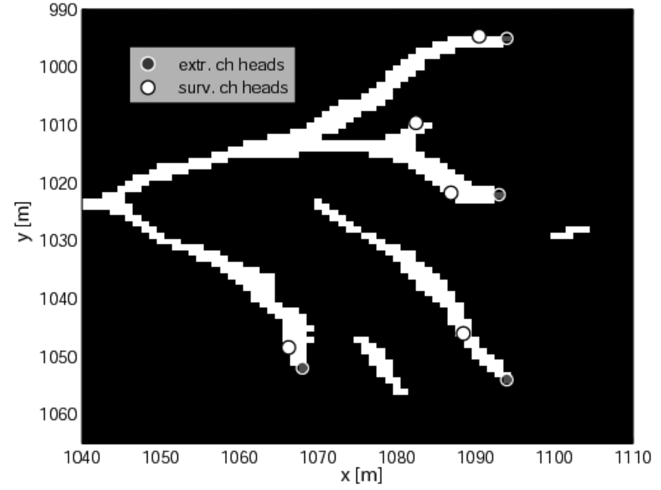
Data from Montgomery and Dietrich [1989]

Channel heads detection



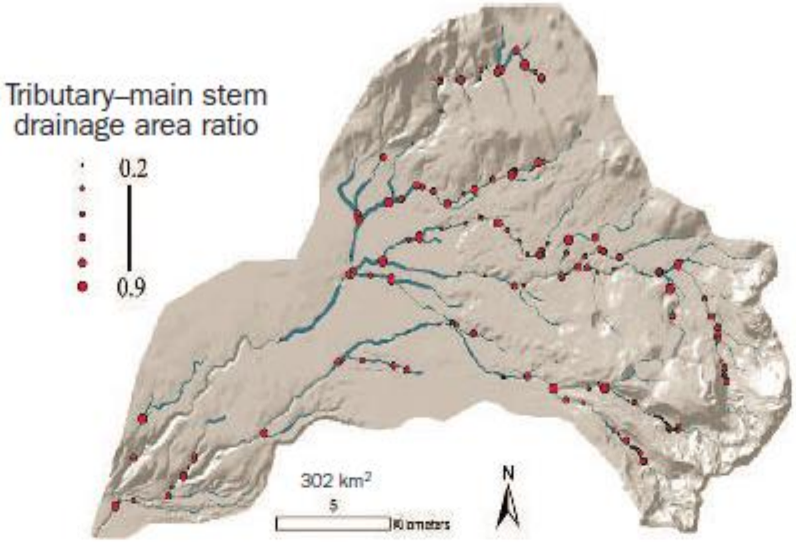


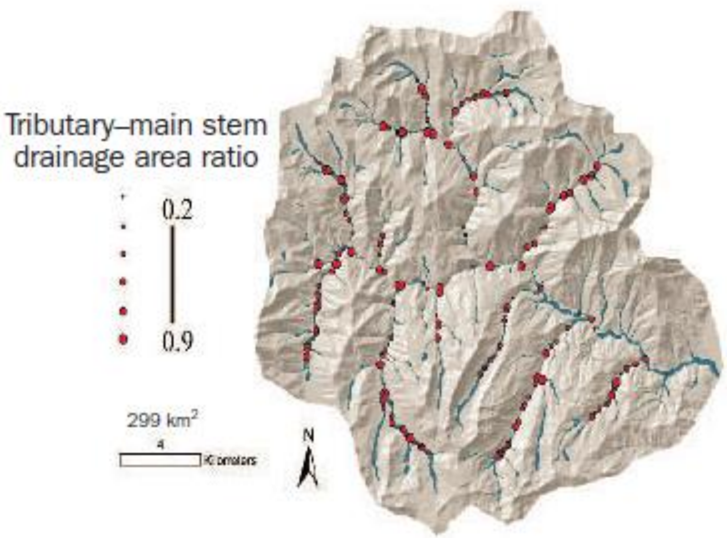




Passalacqua et al., JGR, 2010; WRR 2010

The link between network structure and dynamics in watershed hydrology

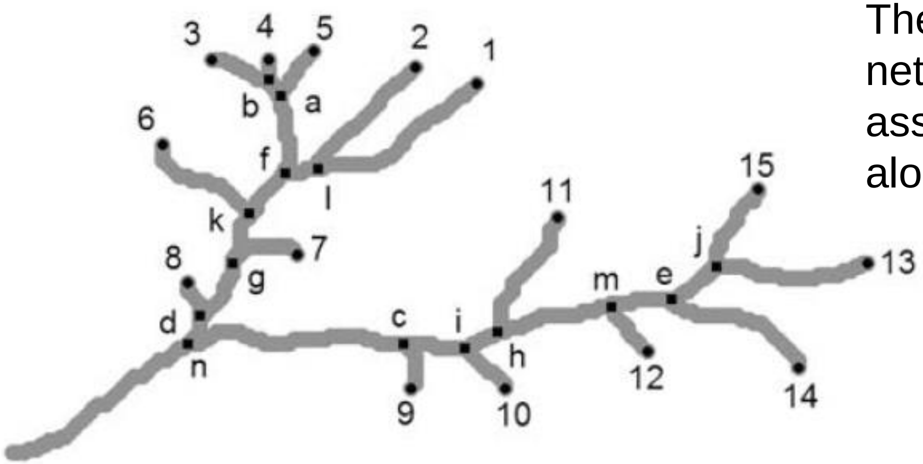




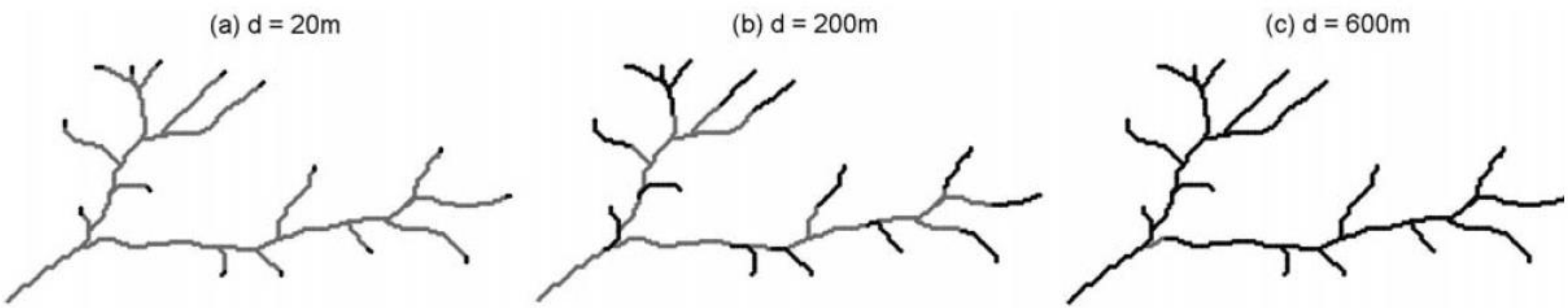
The Network Dynamics Hypothesis [Benda et al., 2004] and the Dynamic Tree approach [Zaliapin et al., 2010] are examples that link basin shape and network attributes to rainfall-runoff dynamics and habitat heterogeneity.

Network Dynamics Hypothesis: Important role of channel junctions as hot-spots of system dynamics. Hypotheses developed to link network and watershed structure to the propagation of fluxes and their impact on the ecosystem.

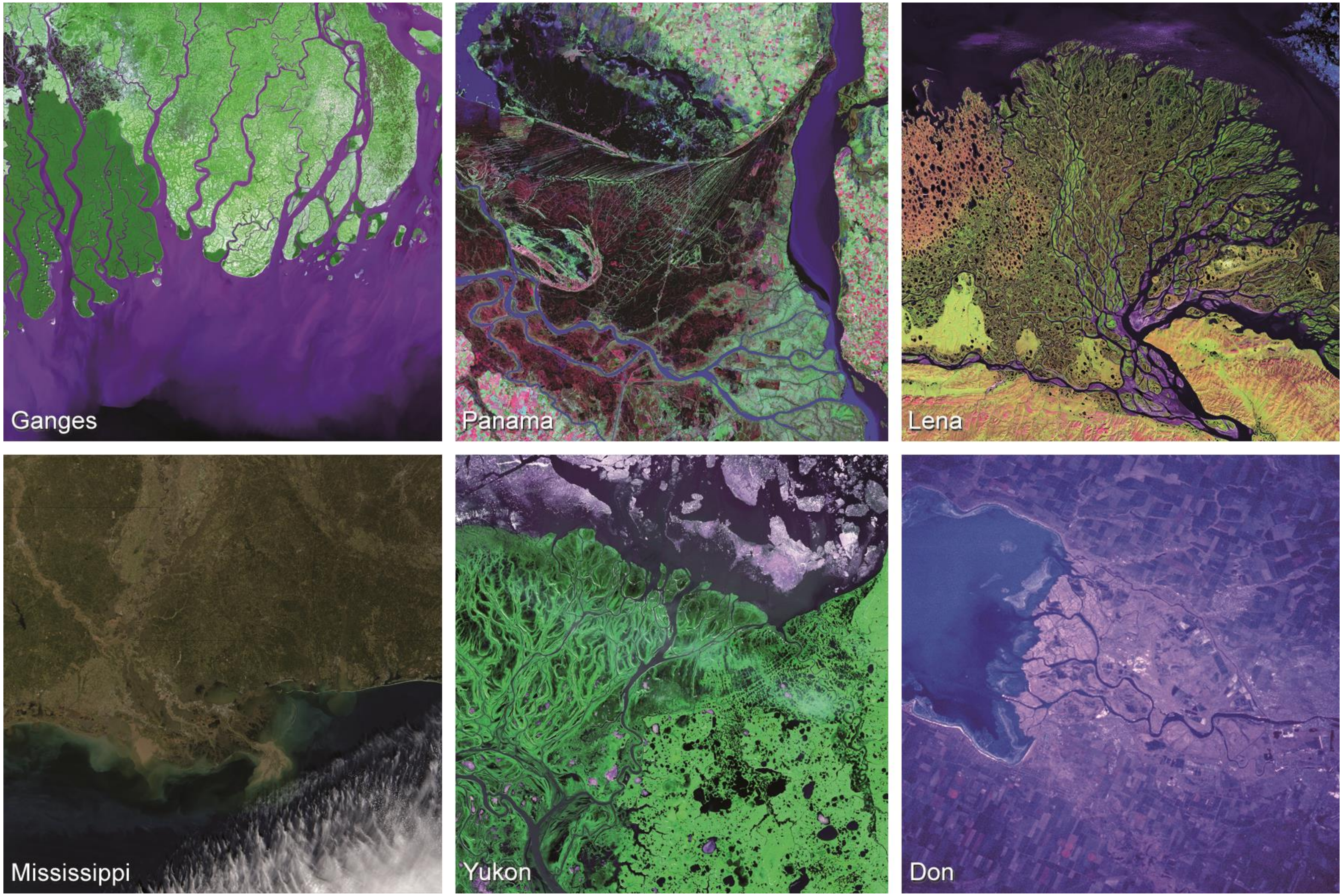
The link between network structure and dynamics in watershed hydrology



Dynamic Tree approach [Zaliapin et al., 2010]: The static geometric structure of the drainage network is described by the static tree, while the associated dynamic tree describes the transport along the static tree.

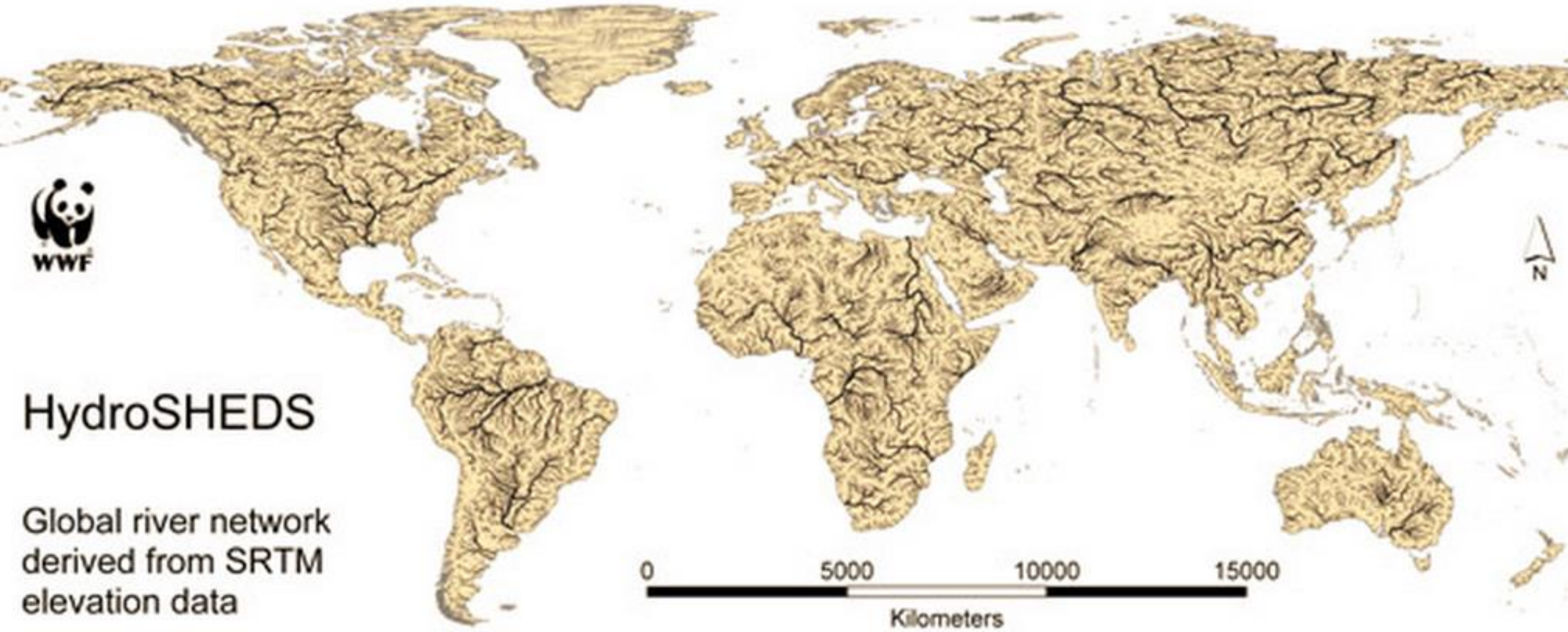


Delta distributary networks



The link between network structure and dynamics in deltaic systems

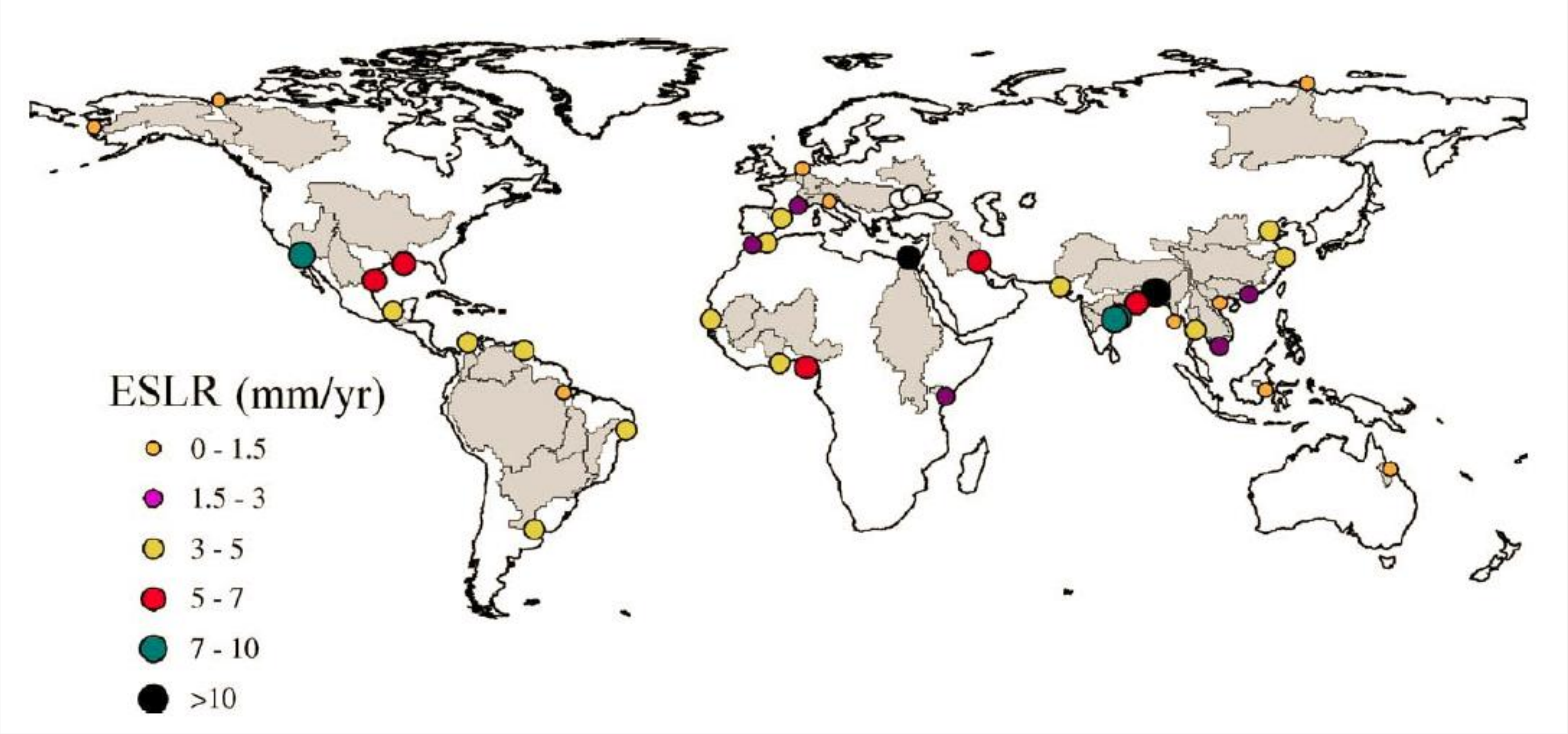
Similar work on deltaic systems yet to be developed: (i) deltas often quite large in size, (ii) common channel extraction algorithms such as D8 fail, (iii) received wider (interdisciplinary) attention only in recent years. Floods have motivated hydrologists to look at river network structure.



Global hydrography dataset HydroSHEDS (delta secondary channels not traced) [Lehner et al., 2008; Lehner and Grill, 2013].

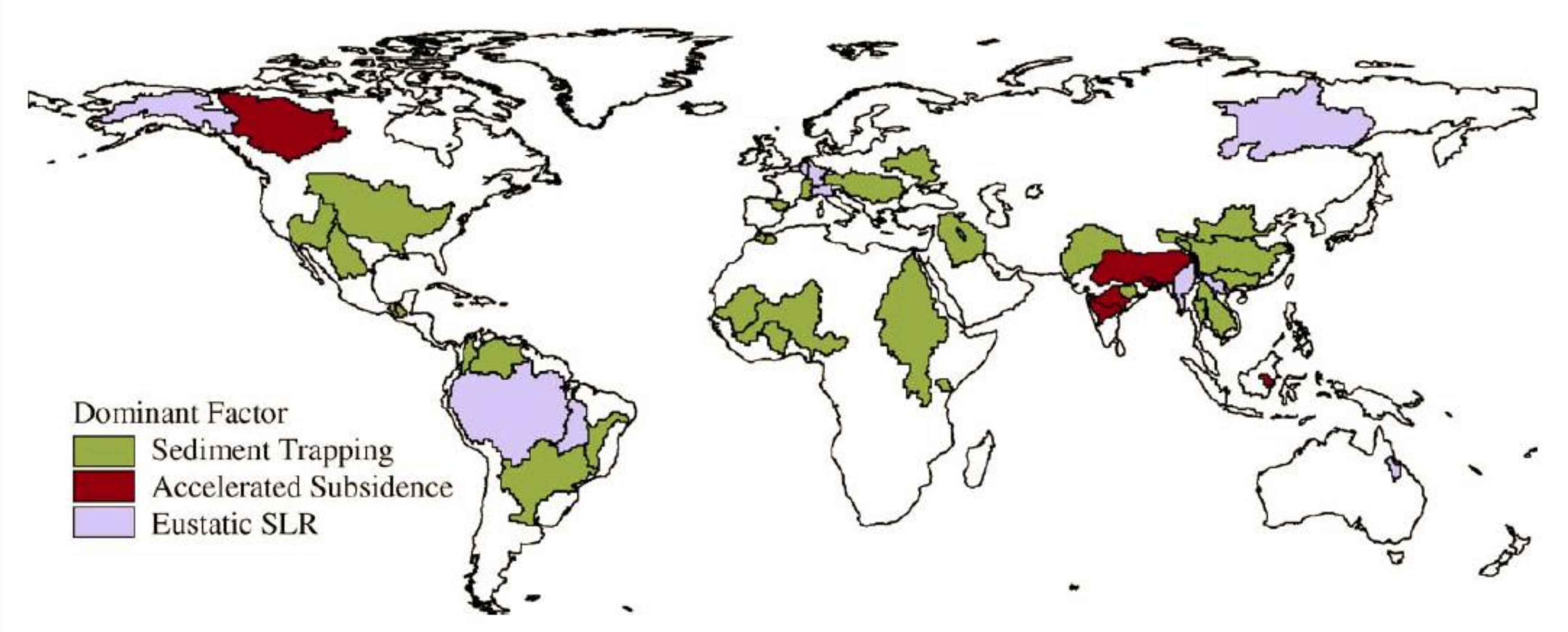
Deltas as fragile systems

Highest ESLR estimates for deltas in South Asia (densely populated, agriculturally active, strongly regulated drainage basins).



Global distribution of ESLR (Effective Sea Level Rise) under contemporary baseline conditions [Ericson et al., 2006].

Deltas as fragile systems



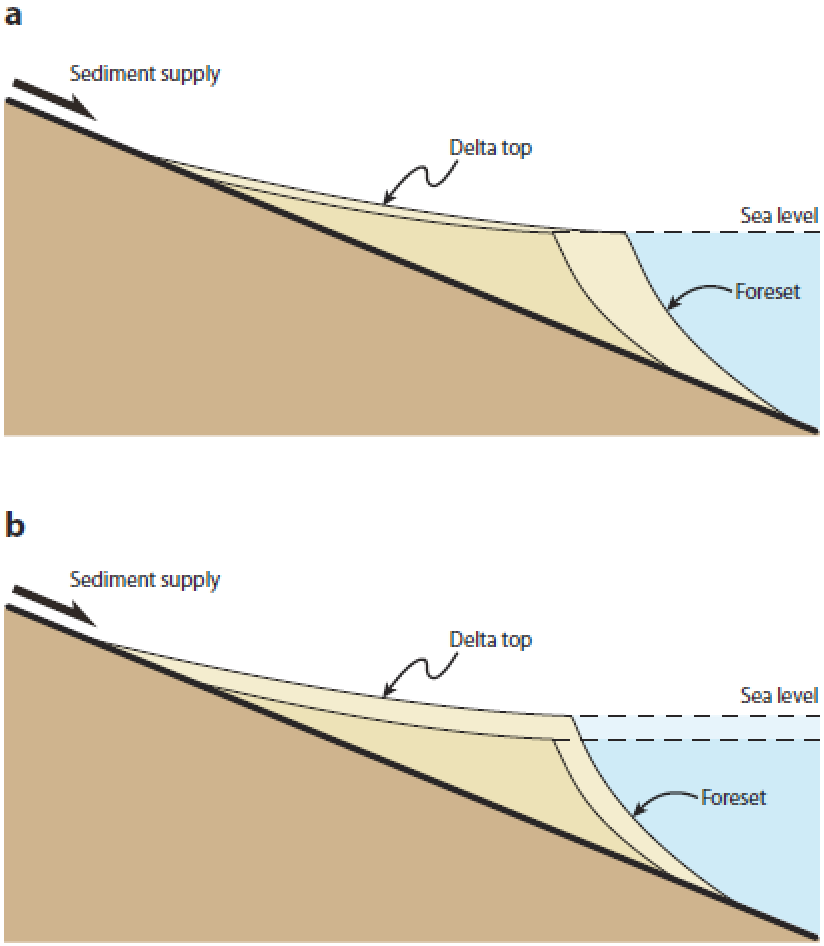
Dominant factor in estimate of ESLR. Sediment trapping dominant factor for 27 deltas, eustatic sea-level rise for 8, accelerated subsidence for 5 [Ericson et al., 2006].

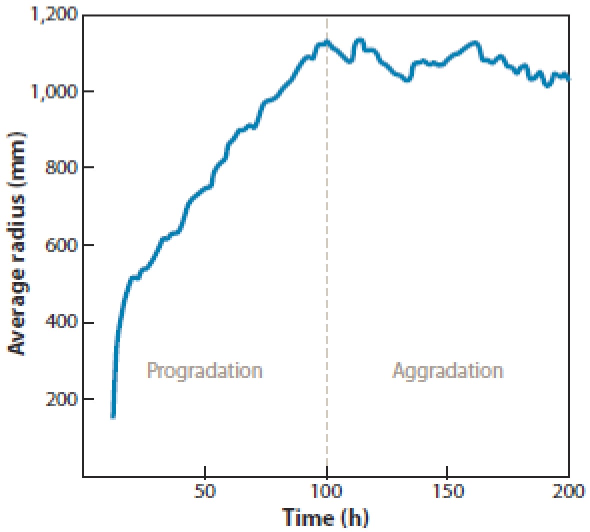
Coastal Louisiana land loss

4900 km^2 of coastal wetland loss since 1900 [Day Jr. et al., 2007] & more is predicted. Red areas indicate land lost since 1932 and the yellow is projected land loss
The predicted land growth is limited to the two deltas fed by the Atchafalaya River.

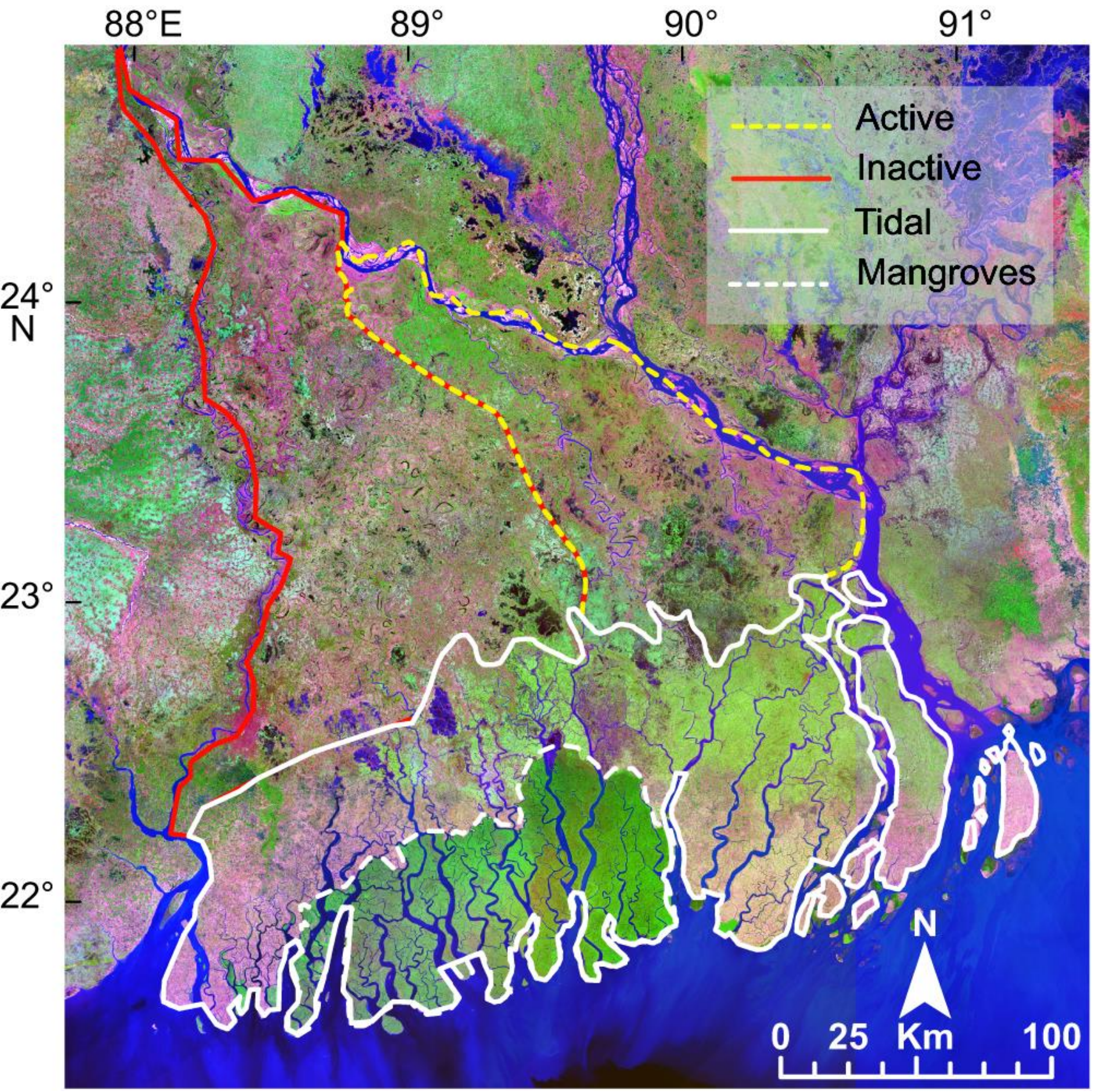
Deltas as resilient systems

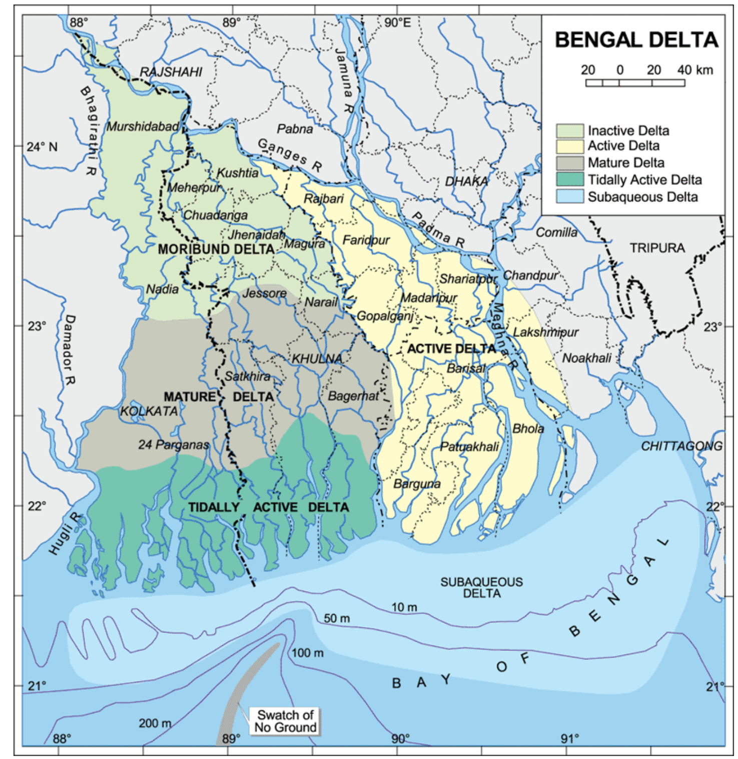
Under the right conditions deltas are also resilient, capable of adapting to a changing environment and recovering from damage caused by extreme events such as storms [Paola et al., 2011].





How much information can be extracted from 2D maps?

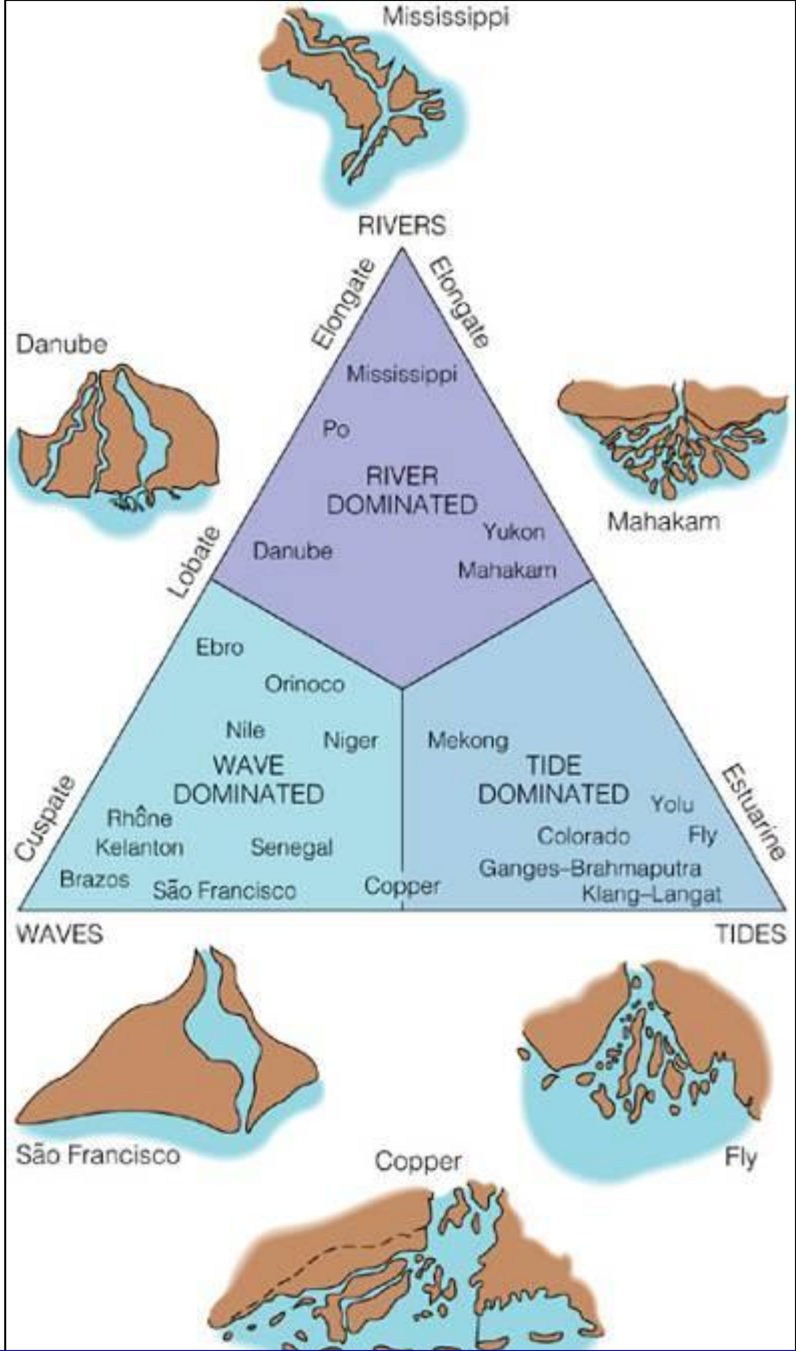




Passalacqua, Lanzoni, Rinaldo, Paola, J. Geophys. Res., 2013

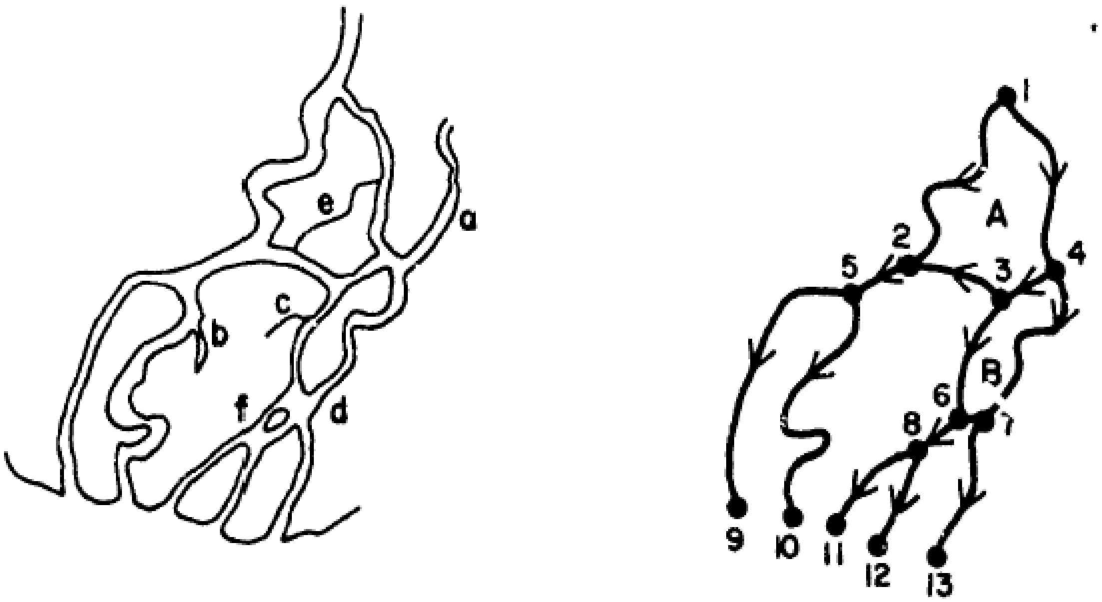
Delta network structure

Wright and Coleman [1972] identified river discharge and wave strength among the fundamental drivers of delta morphology, initiating the ternary classification according to rivers, waves, and tides. More complex classifications proposed later [Elliot, 1986; Hart, 1995; Syvitski, 2005] are still challenged by the fact that forcing factors can vary in space and time.



Delta network structure

Smart and Moruzzi [1972]: representation of deltas as a graph. Several functions of vertex and link number applied to few deltas manually extracted at coarse resolution.



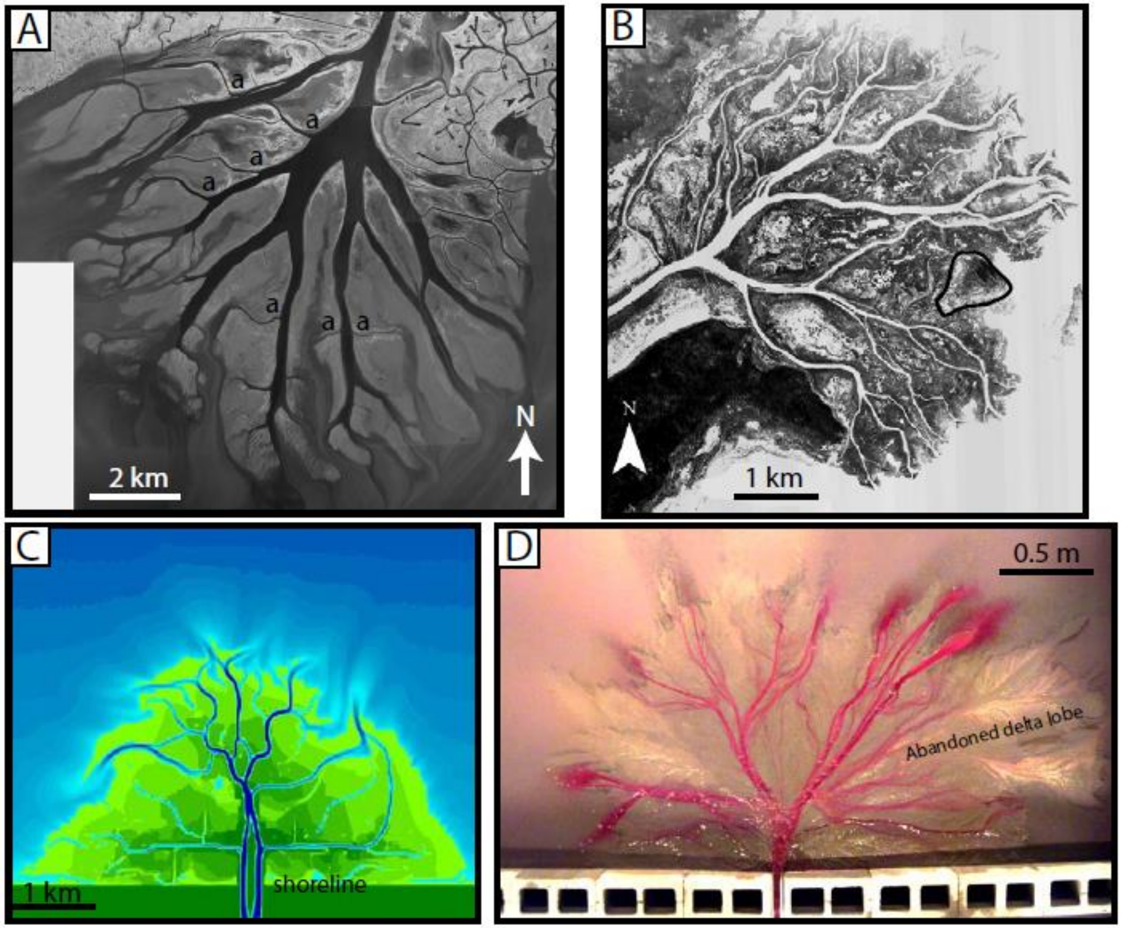
(a) (b)

Analysis of five natural deltas showed some common topologic and geometric features.

Same analysis extended to a larger number of deltas [Morisawa, 1985] showed the difficulty of classifying delta morphology.

Delta network structure

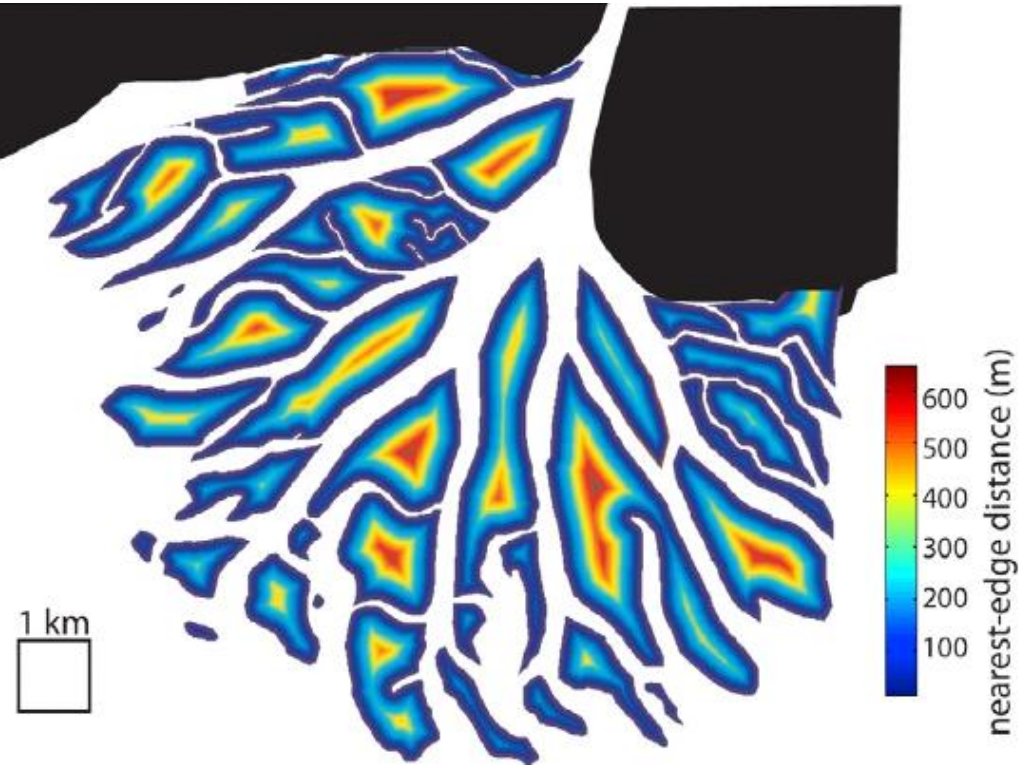
Edmonds, Paola et al. [2011]: five metrics (fractal dimension, distribution of island size, nearest-edge distance, fluxes at shoreline, nourishment area) proposed to characterize deltas.

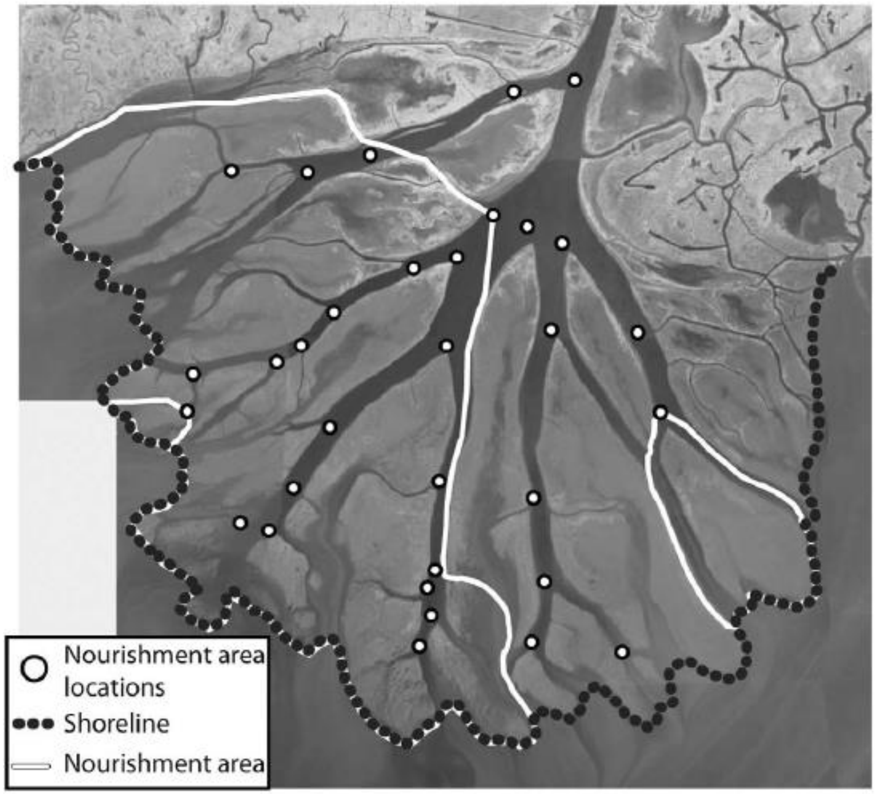


Sediment focused approach tested on four deltas (two natural, one experimental, one numerical)

Delta network structure

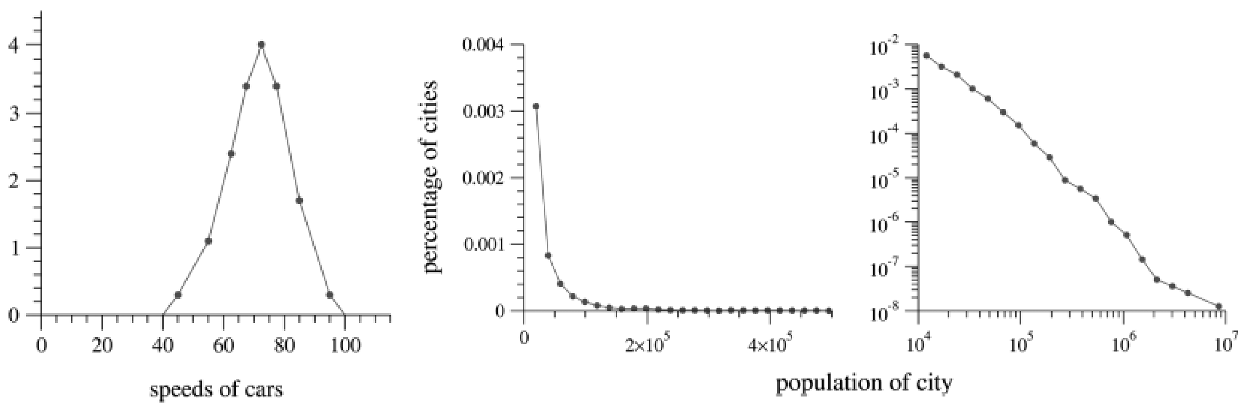
Edmonds, Paola et al. [2011]: five metrics (fractal dimension, distribution of island size, nearest-edge distance, fluxes at shoreline, nourishment area) proposed to characterize deltas.



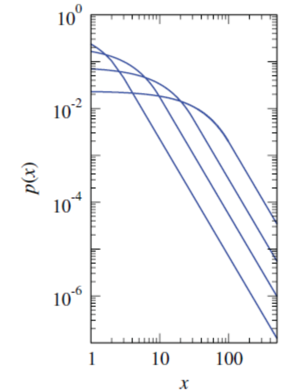


Statistical analysis to identify and interpret delta forming processes

- Extraction of channel network from satellite imagery
- Identification of key metrics and channel network descriptors: island area and aspect ratio, nearest-edge distance, channel width, oxbow density
- Statistical analysis of metrics: analysis of the probability density function (pdf) and possible presence of power law behavior

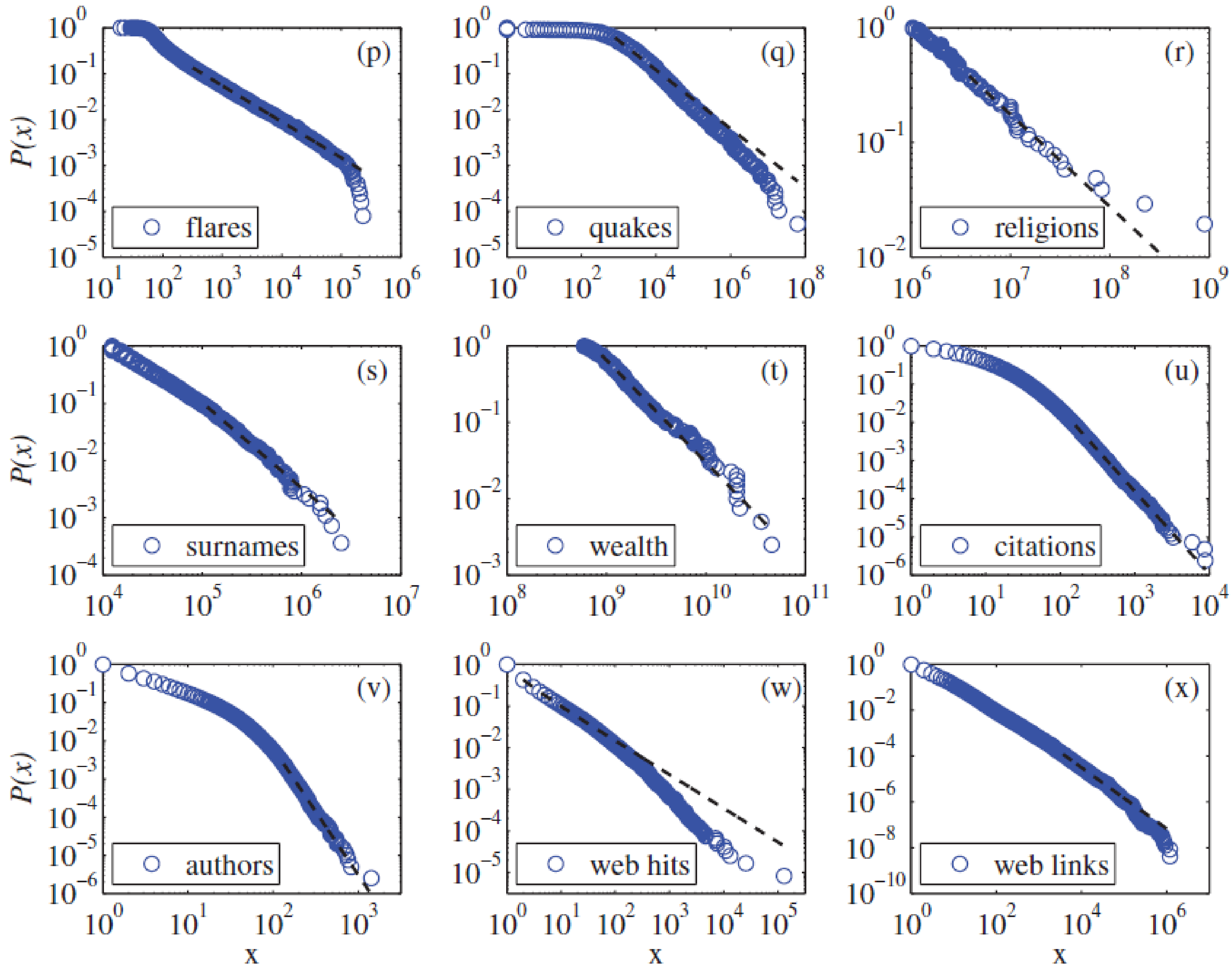


Newman, [2005]



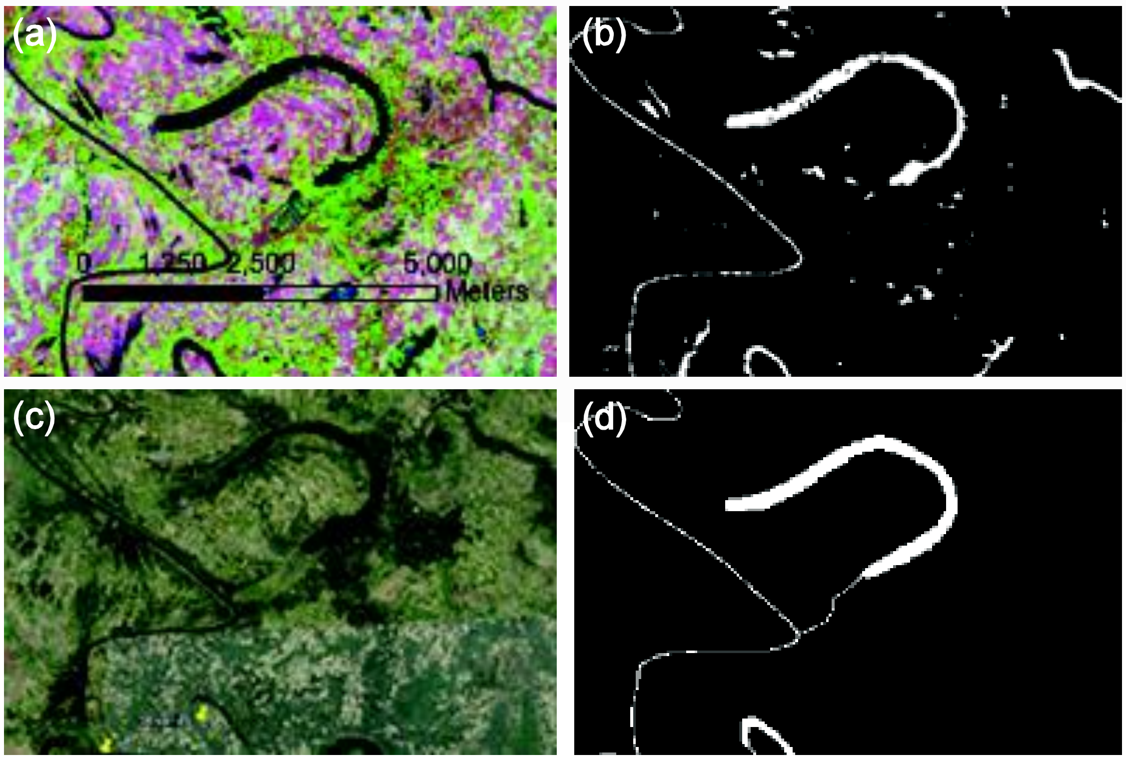
Clauset et al., [2009]

Power-law distributions in empirical data



Clauset et al., [2009]

Deltaic network extraction from satellite imagery



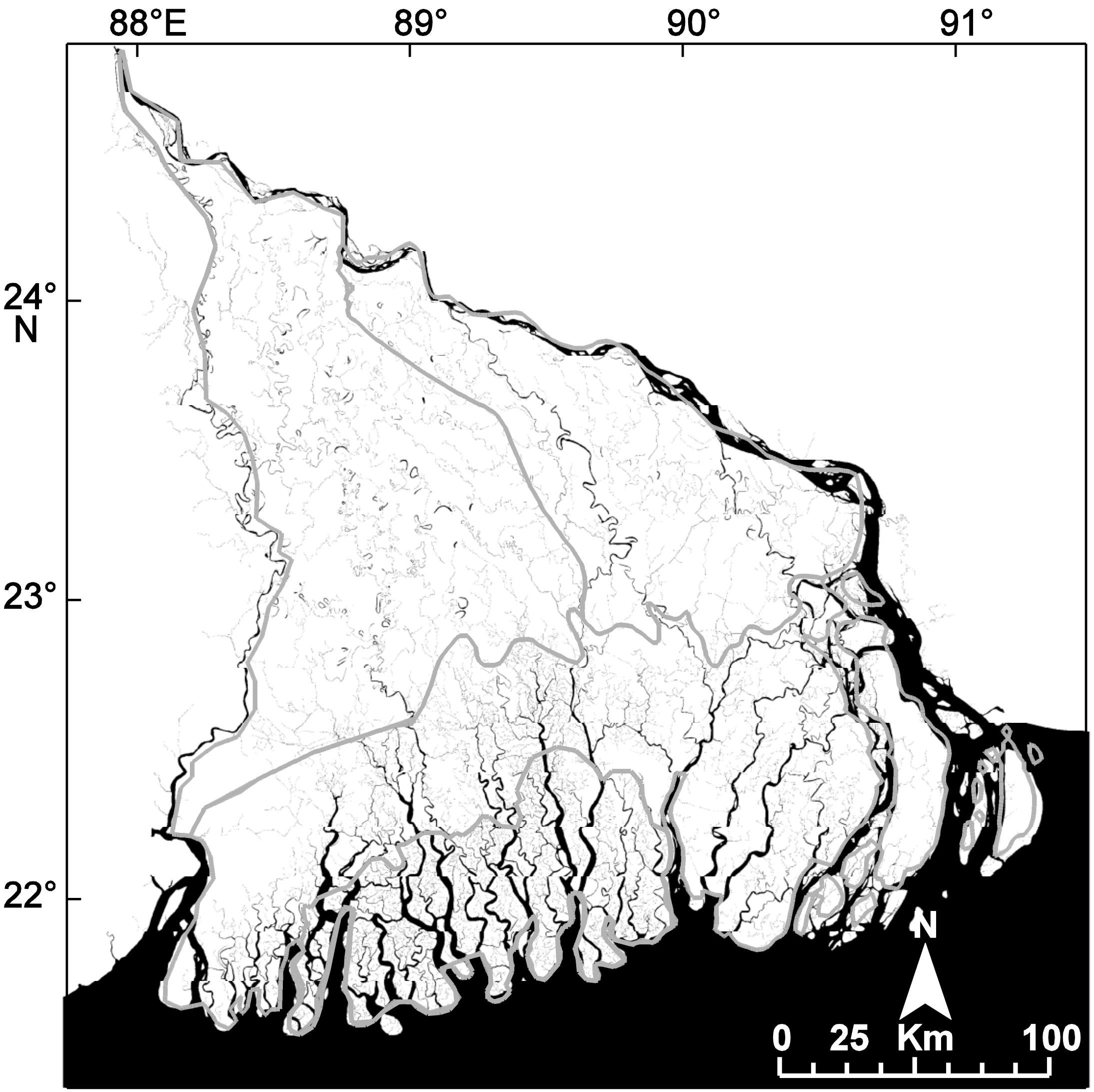
Fully automatic feature extraction technique hard to apply in coastal areas

Approach taken here: unsupervised and supervised classification in ArcGIS

The binary classification in water and land pixels can result in the detection of several spurious features and isolated water sources

Passalacqua, Lanzoni, Rinaldo, Paola, J. Geophys. Res., 2013

Deltaic network extraction from satellite imagery



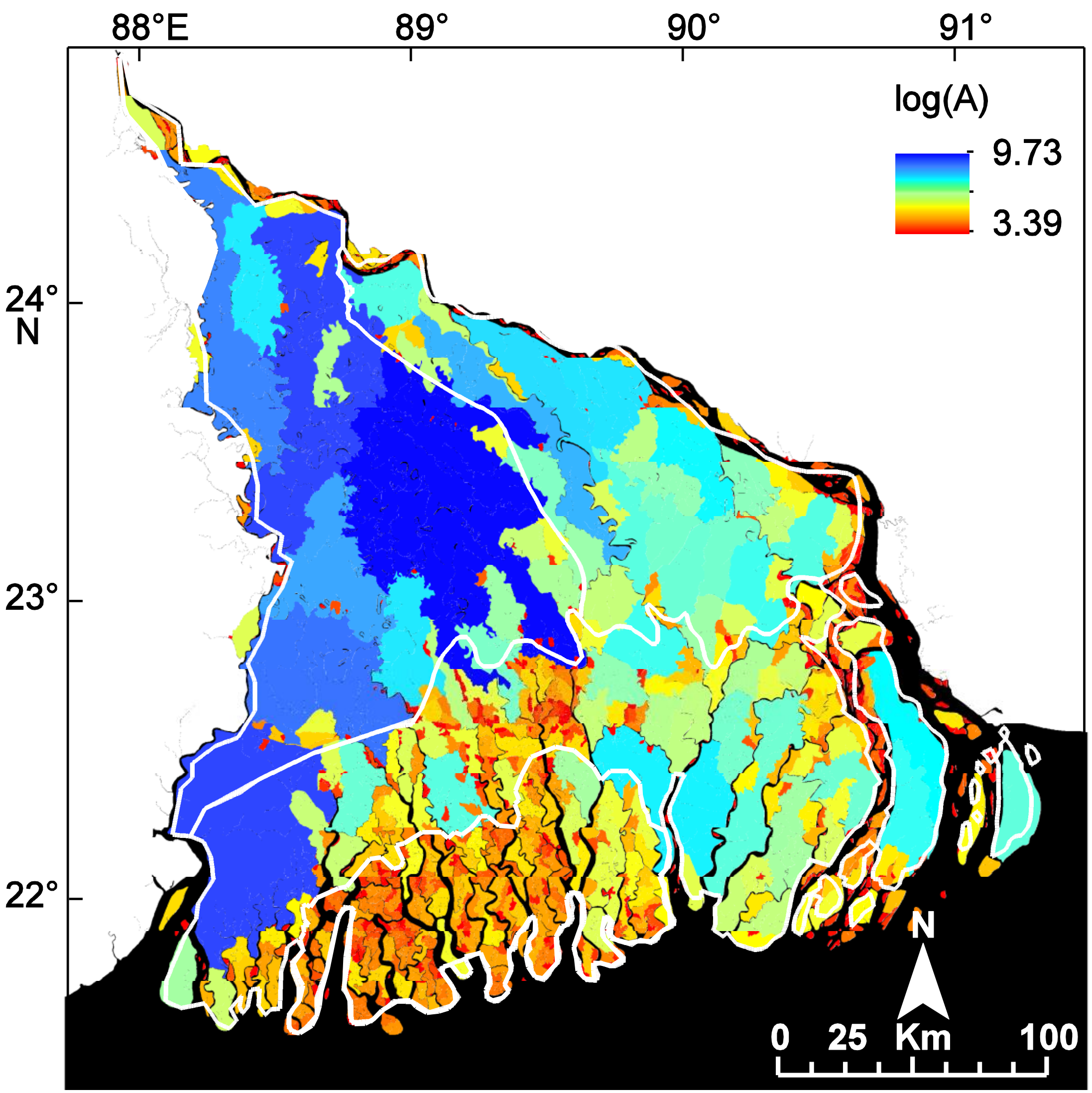
Channel morphology and channel density vary among different portions of the delta

Drainage density particularly high within tidally dominated region

Large number of oxbows present in the moribund and mature portions

65% of the oxbow lakes seem to be drained by tidal channels that extend upstream from the coast

Island geometry analysis



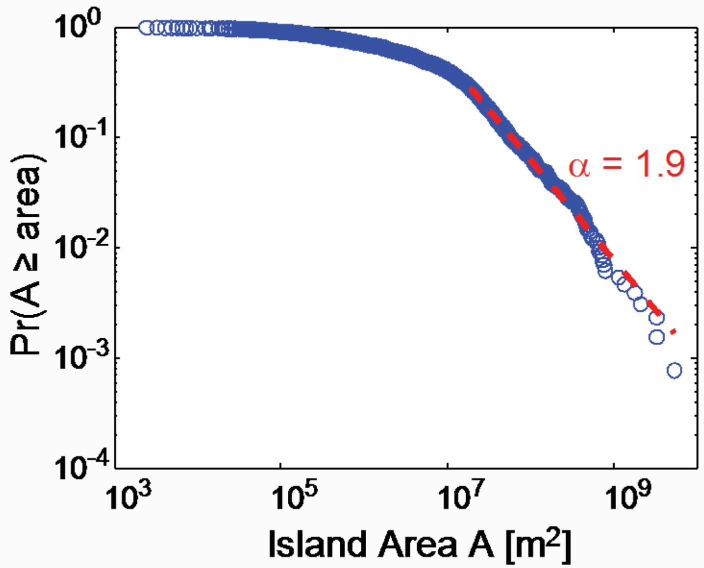
Islands associated with channel morphology and interactions among neighboring channels

Islands of larger area located within upper portion of the delta

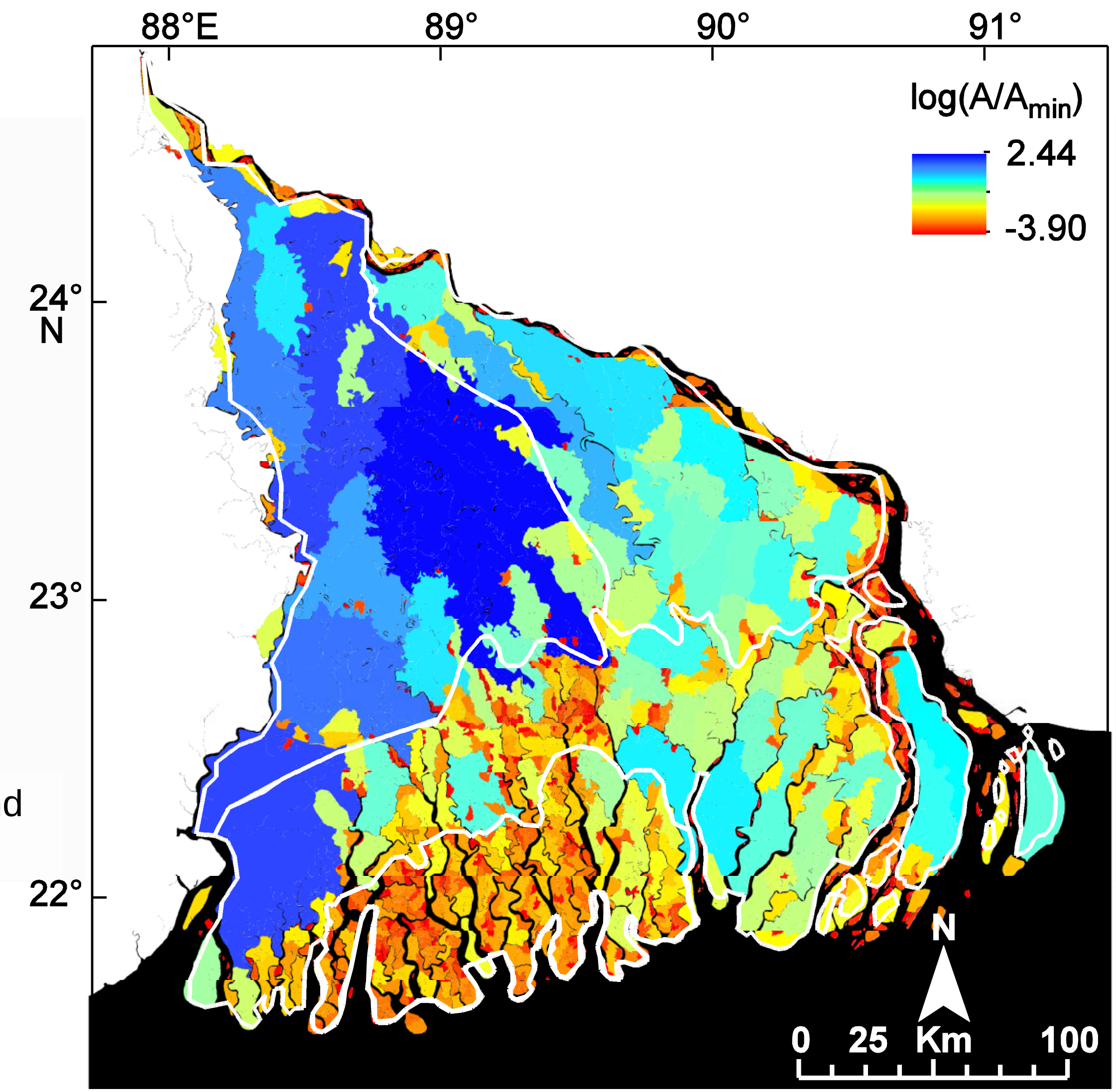
Smaller islands mainly located near the coast

Islands within mangrove forest typically smaller than everywhere else

Island area distribution

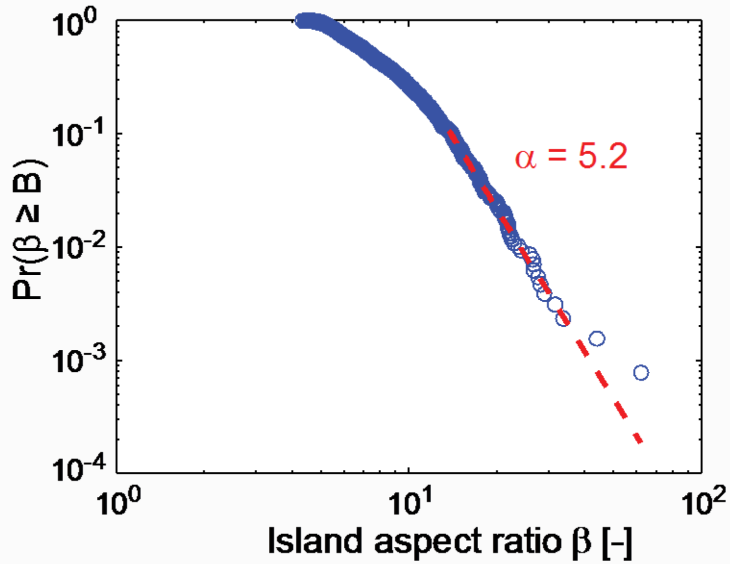


Power law behavior with exponent 1.9 for island area $A > A_{min} = 1.96 \cdot 10^7$ m^2 (p-value 0.78)

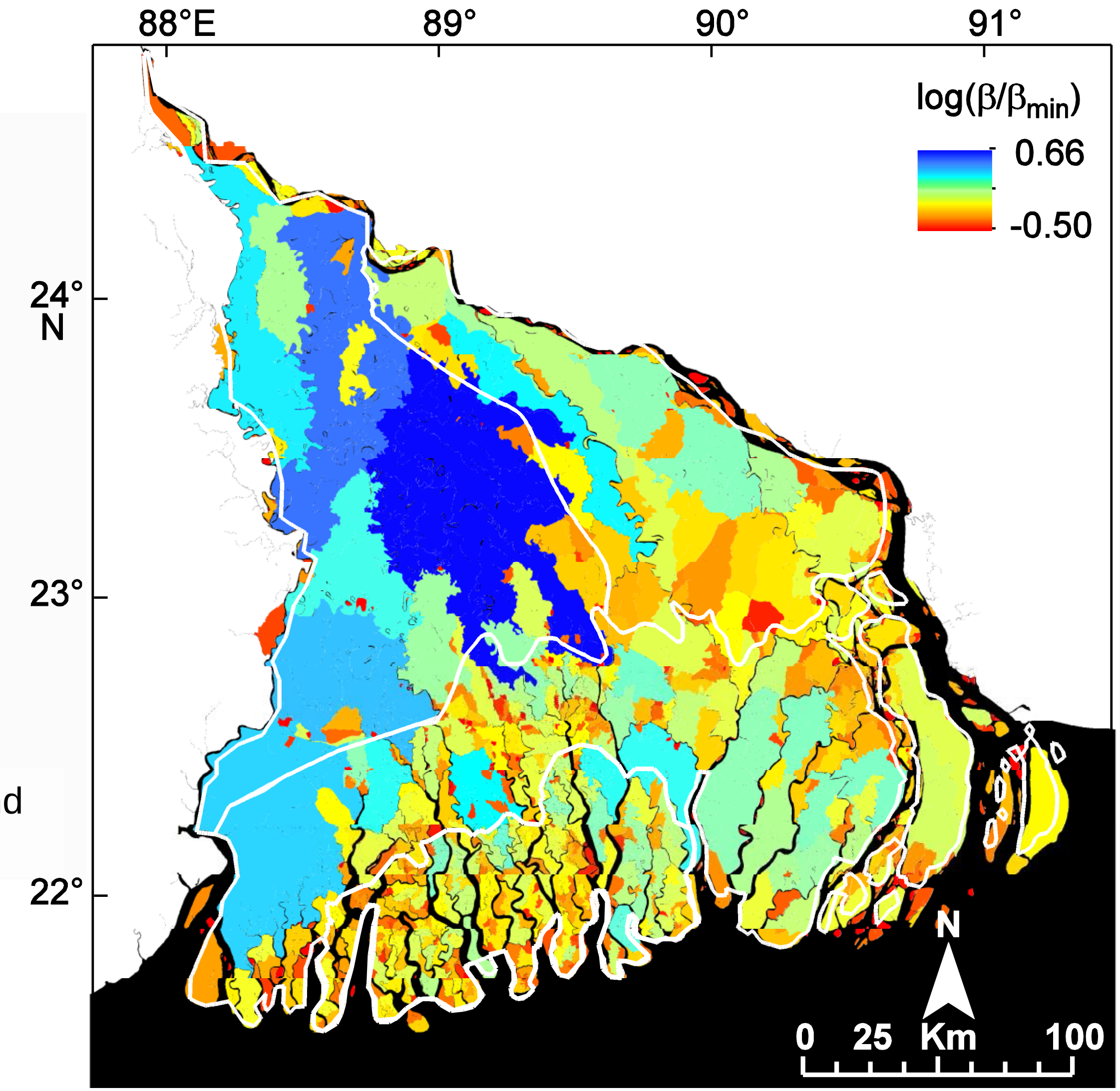


Island shape factor

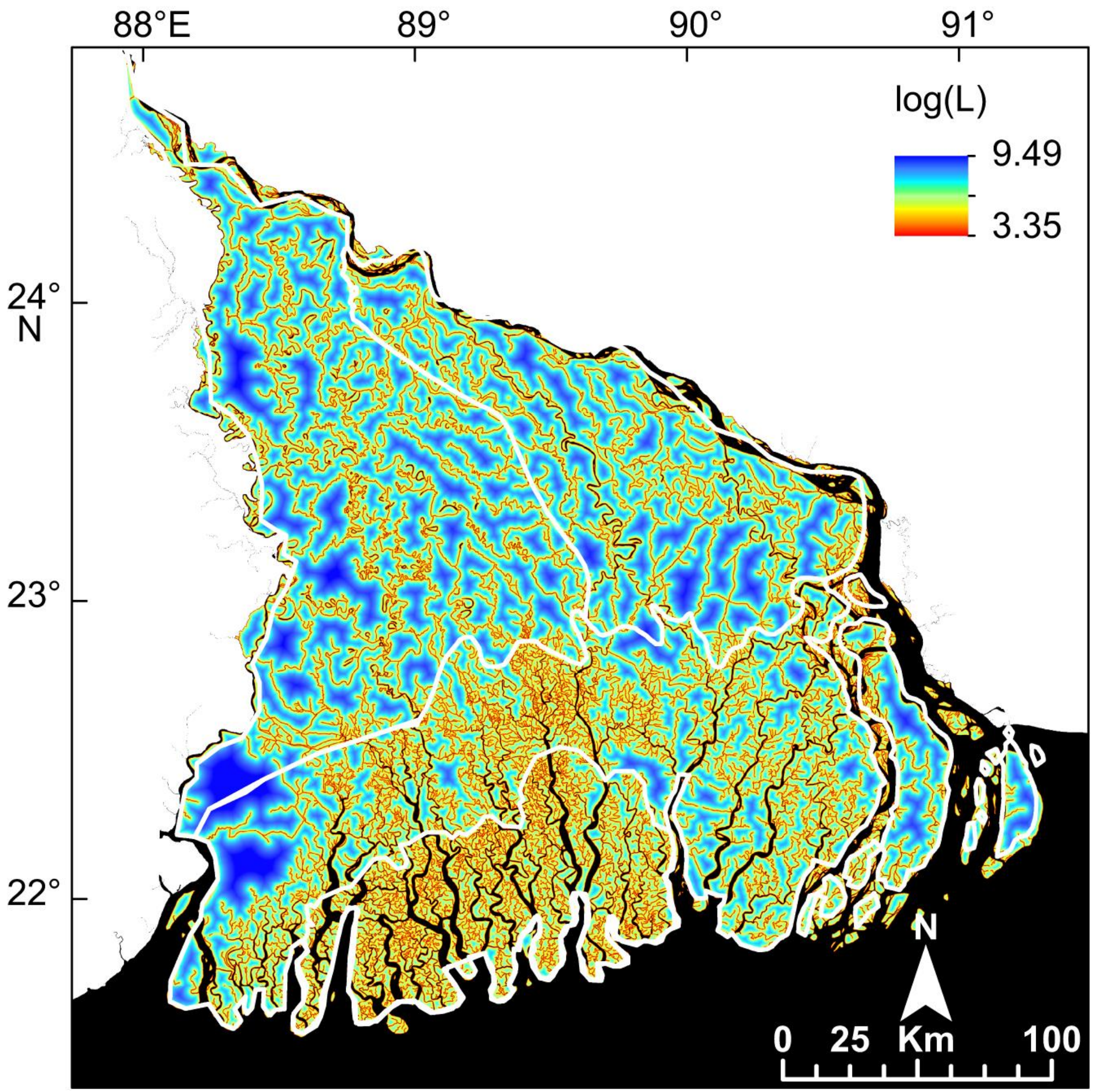
Shape factor $\beta = P$ (wetted perimeter)/$\text{Area}^{0.5}$



Power law behavior with exponent 5.2 for island aspect ratio $\beta > \beta_{min} = 13.7$ (p-value 0.63)



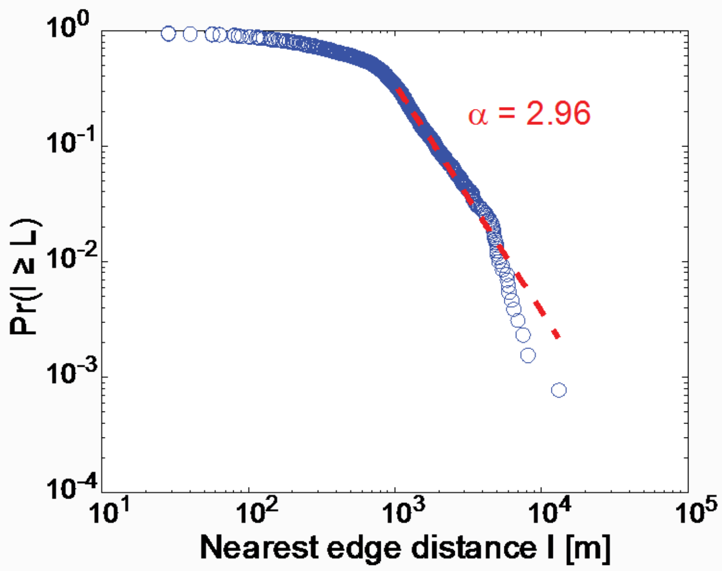
Nearest-edge distance



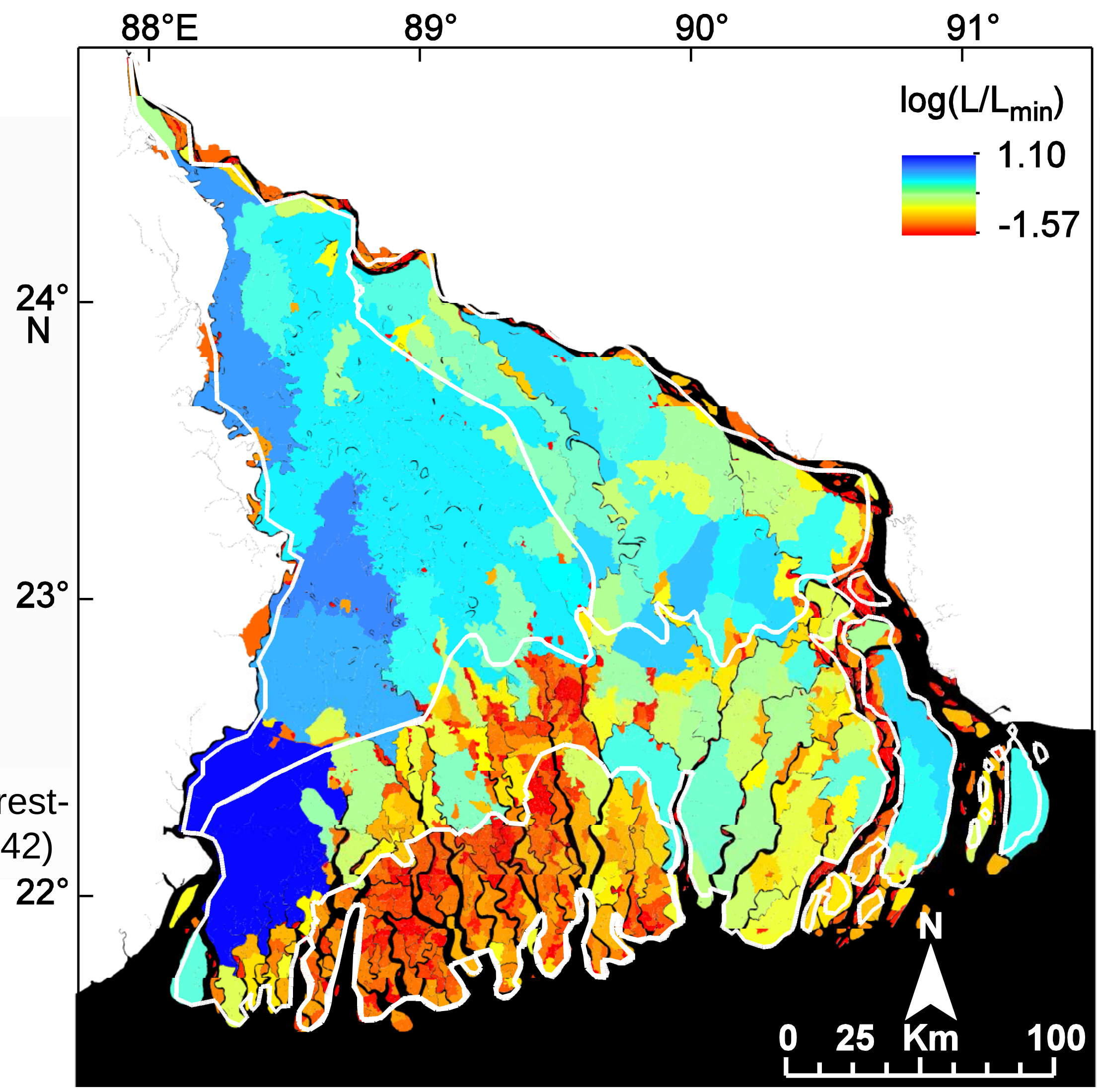
Shortest straight-line distance from nearest source of water [Edmonds et al., 2011]

Smallest values located near the coast, particularly within the mangrove forest

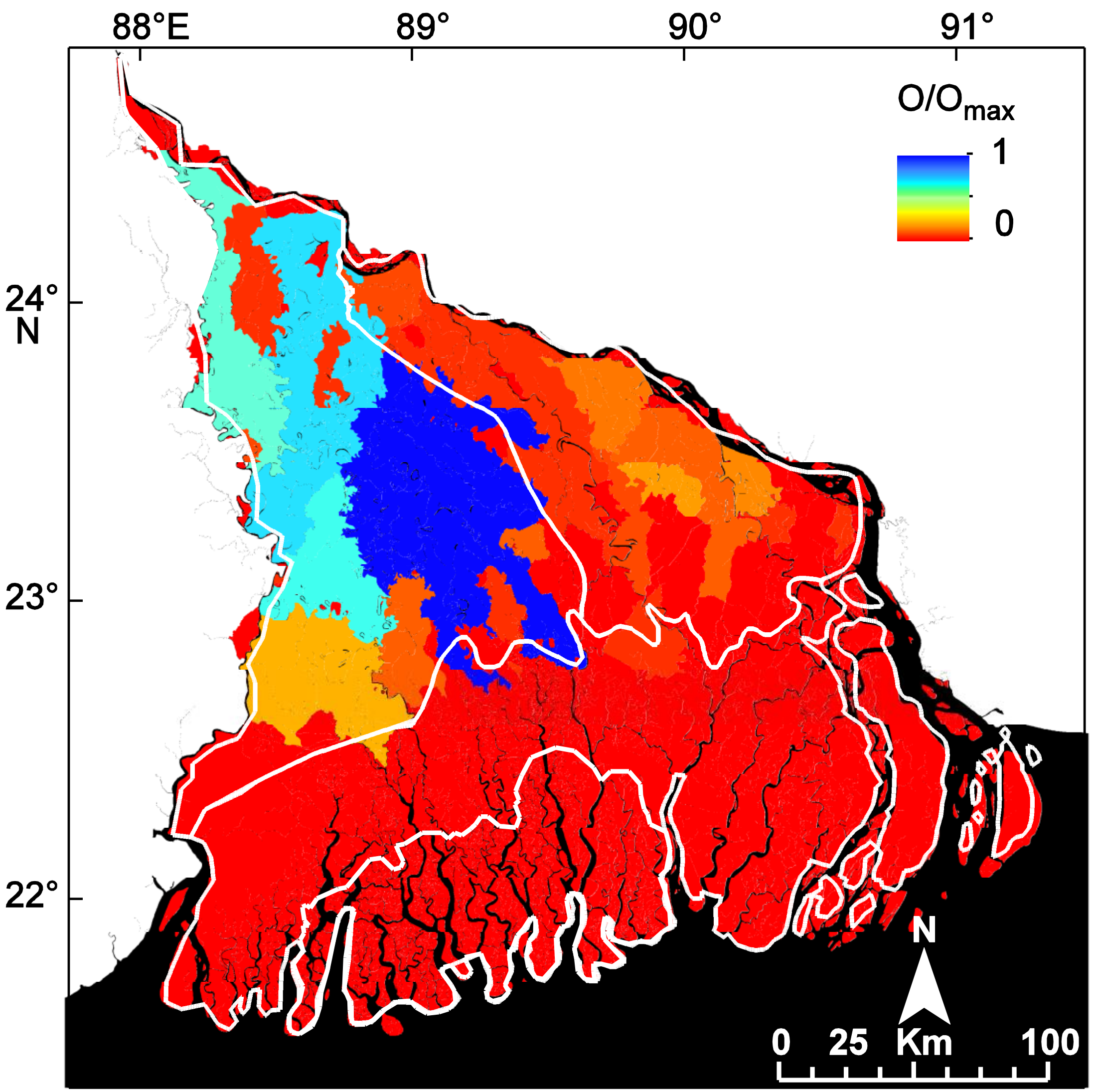
Nearest-edge distance



Power law behavior with exponent 2.96 for nearest-edge distance $\ell > \ell_{min} = 1.054 \cdot 10^3$ m (p-value 0.42)

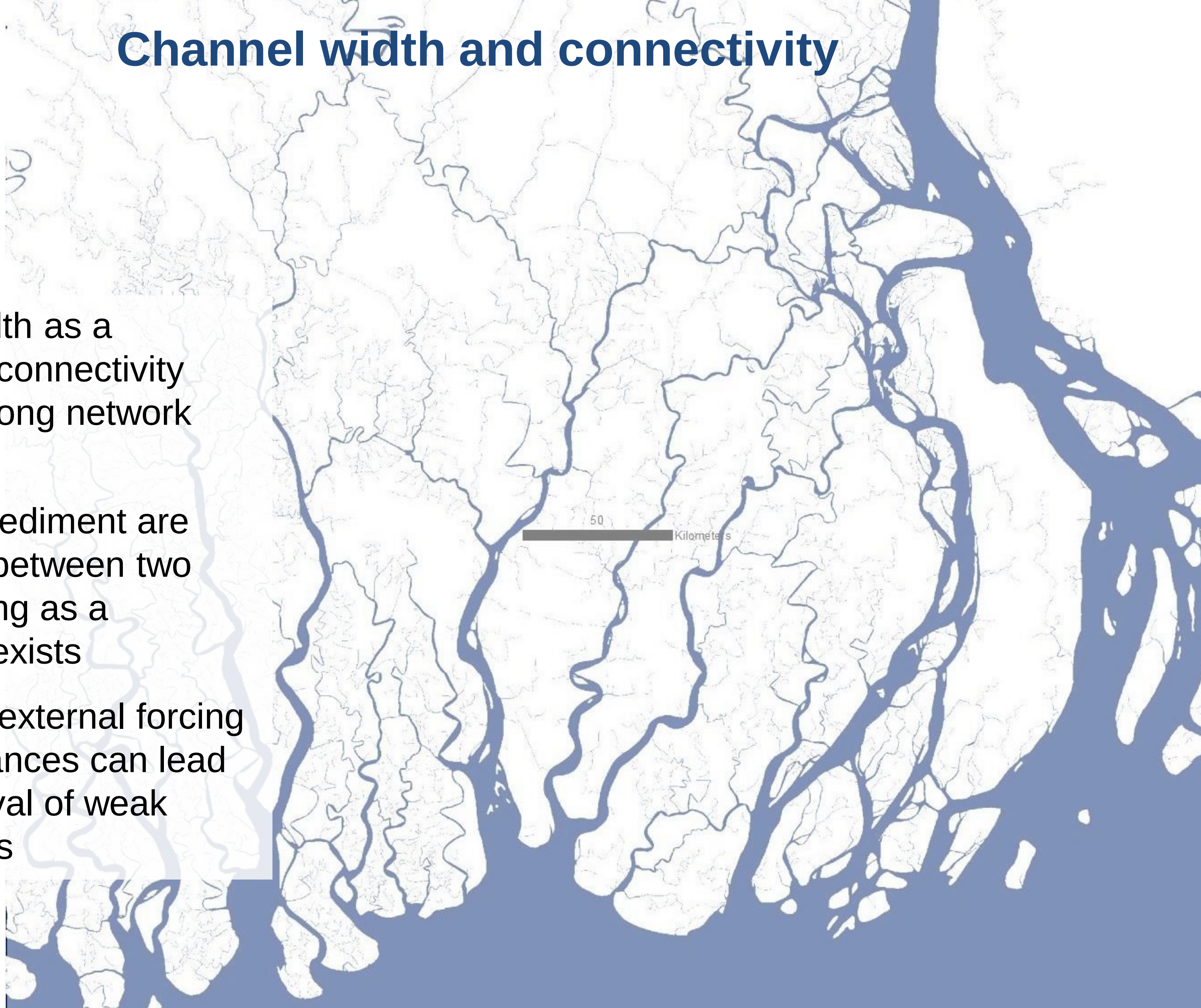


Oxbow density



All the oxbows are located far from the coast and are concentrated in the northwestern region. The area where oxbows are present coincides with the inactive region. Likelihood of oxbows to be preserved increases with distance from a channel.

Channel width and connectivity

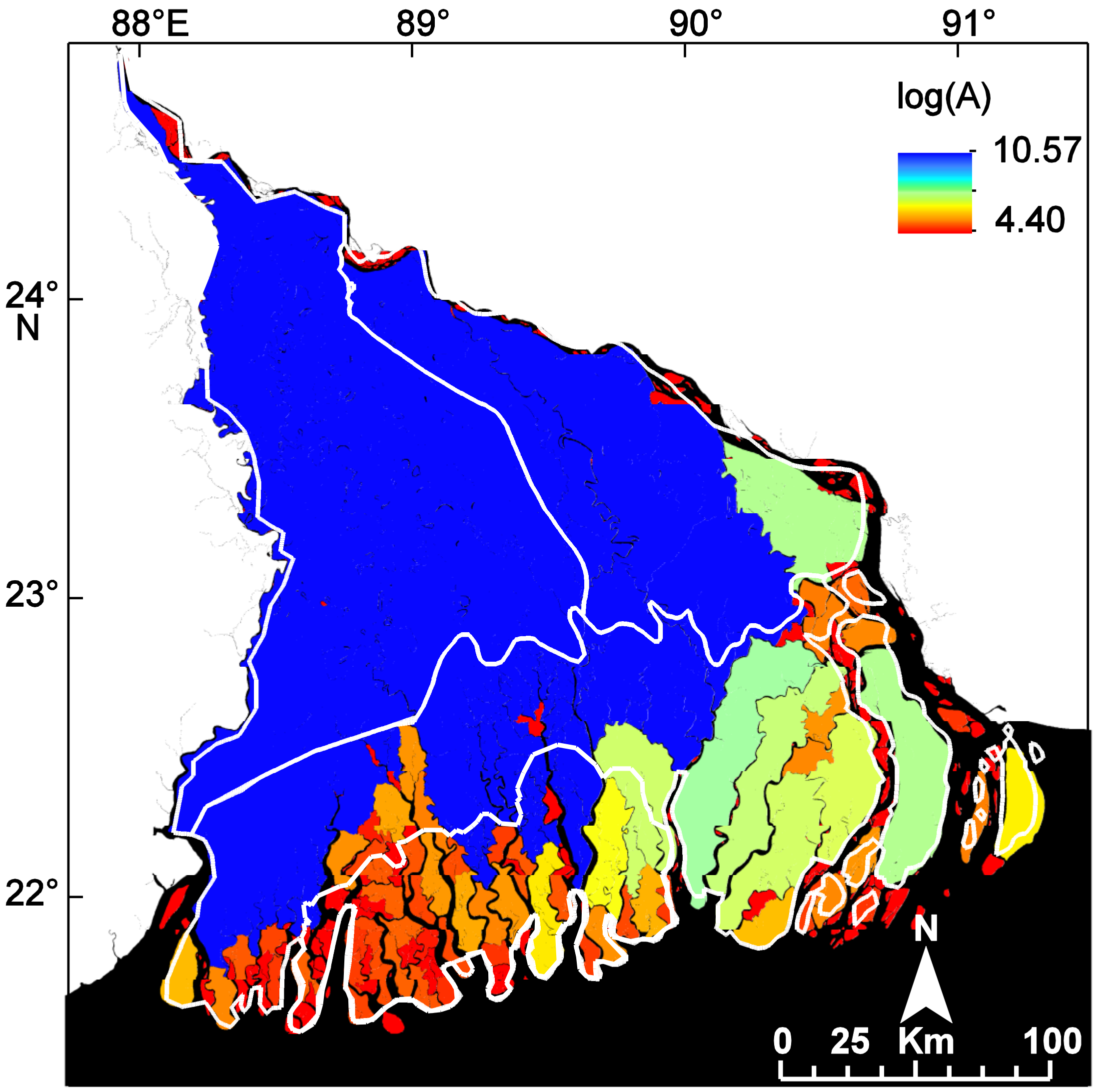


Channel width as a measure of connectivity strength among network nodes

Water and sediment are transferred between two nodes as long as a connection exists

Changes in external forcing and disturbances can lead to the removal of weak network links

Weighted (width) connectivity analysis of channels patterns



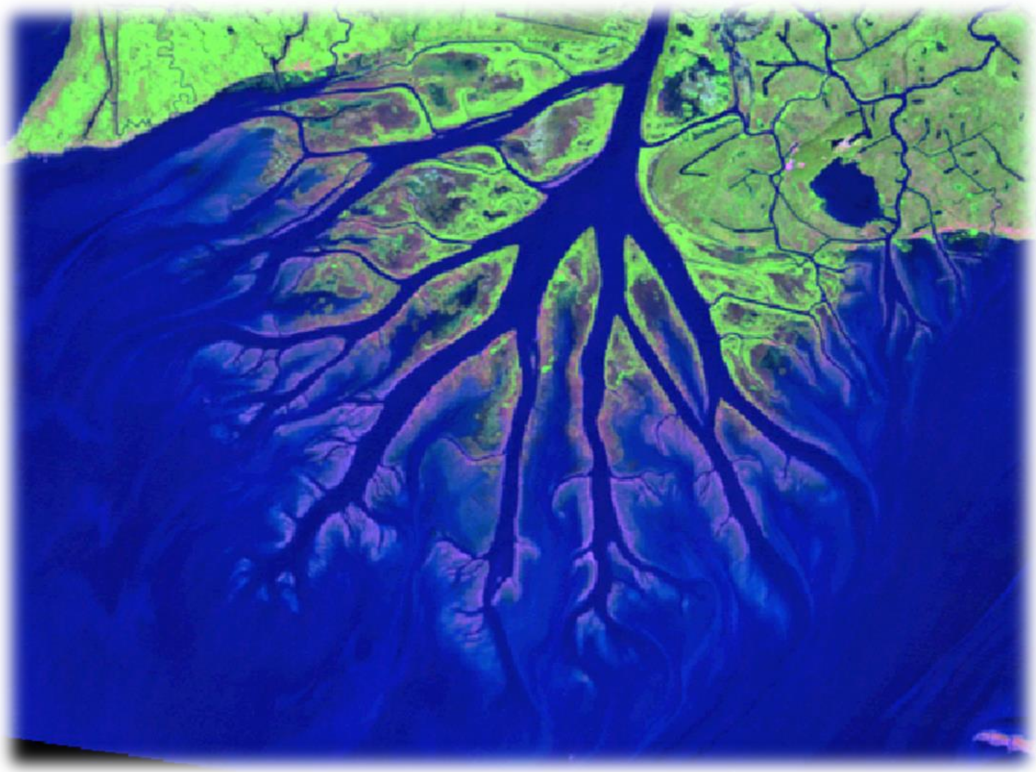
As the weakest links are removed, the upstream portion of the delta behaves as a single island

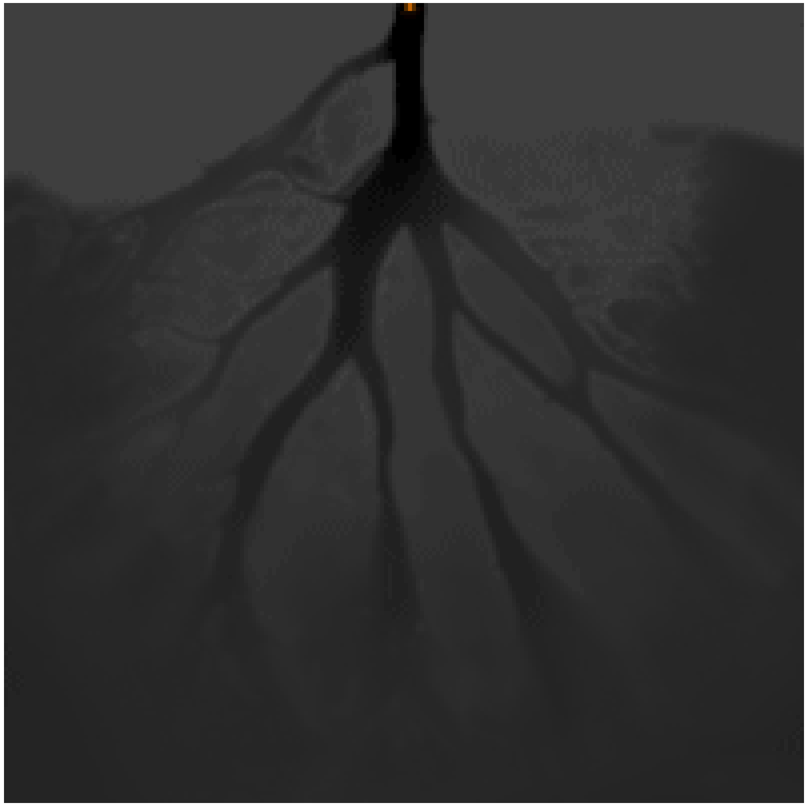
The channels connecting the moribund/mature portion of the delta to the coast are predominantly weak network links

Transport of water and sediment through the moribund/mature portion of the delta occurs via weak connections, likely active only during relatively large floods

The propagation of environmental fluxes through the network

What is the interplay between delta network topology and associated geometry (e.g., island shape) and the transport dynamics of environmental fluxes? Do loopless and looping portions of the network behave the same way? Do inter-channel islands participate in transport dynamics?

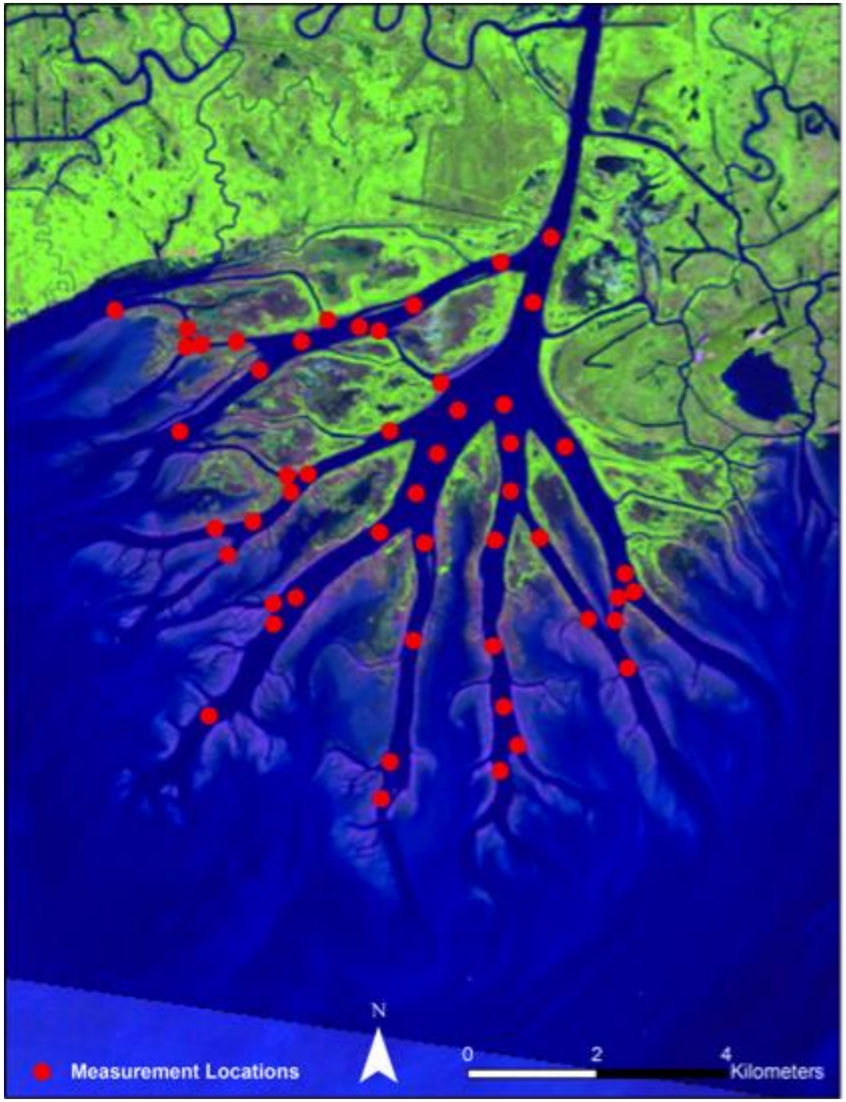




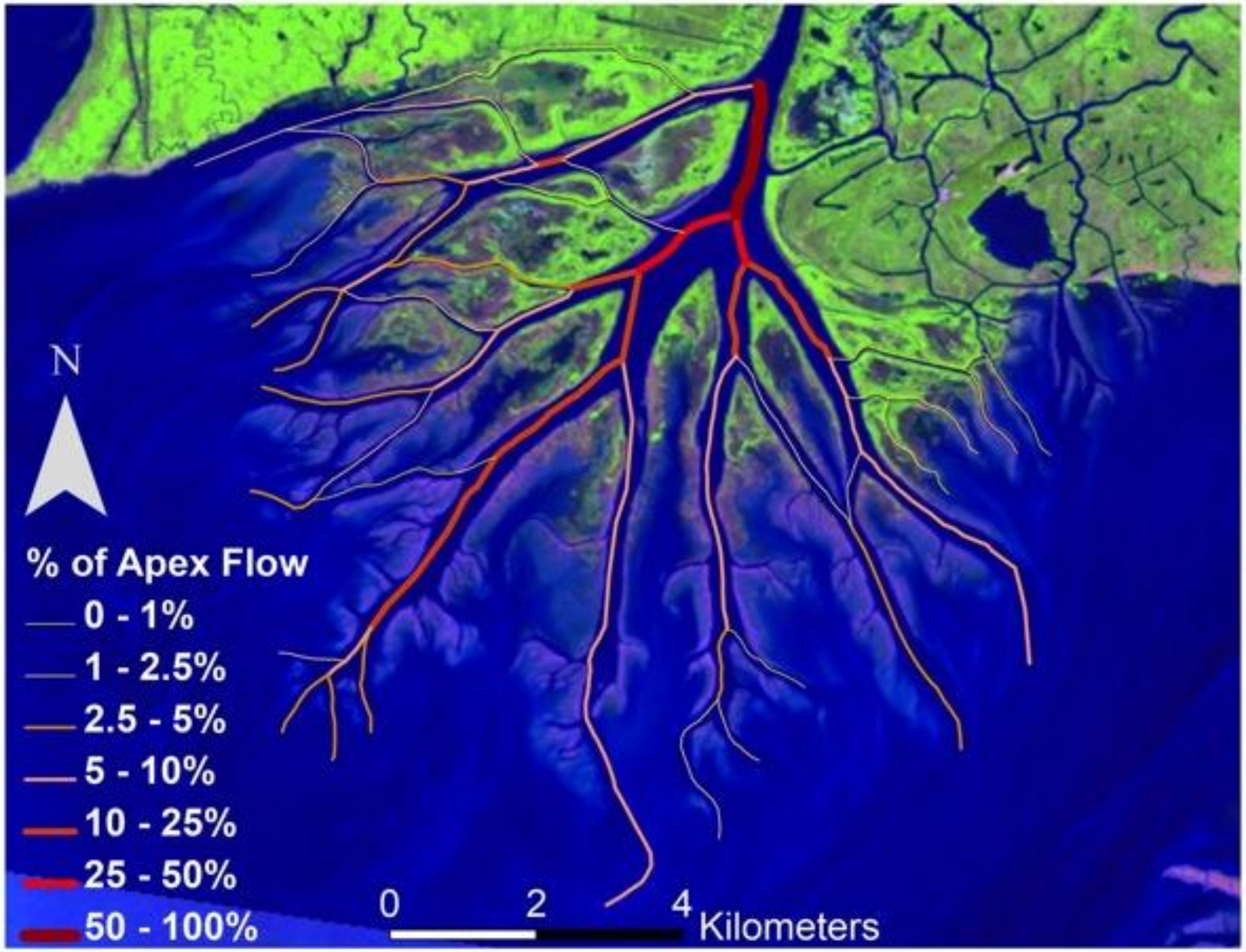
Propagation of environmental fluxes

<u>Hypothesis:</u>

Environmental fluxes (water, sediment, nutrients) are propagated through the delta via both the distributary channels and the inundated island interiors. Island hydraulic residence times are long enough to promote nutrient cycling.

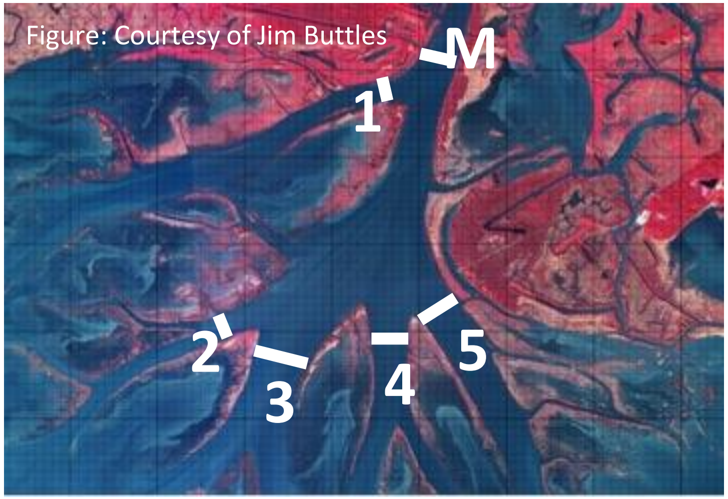


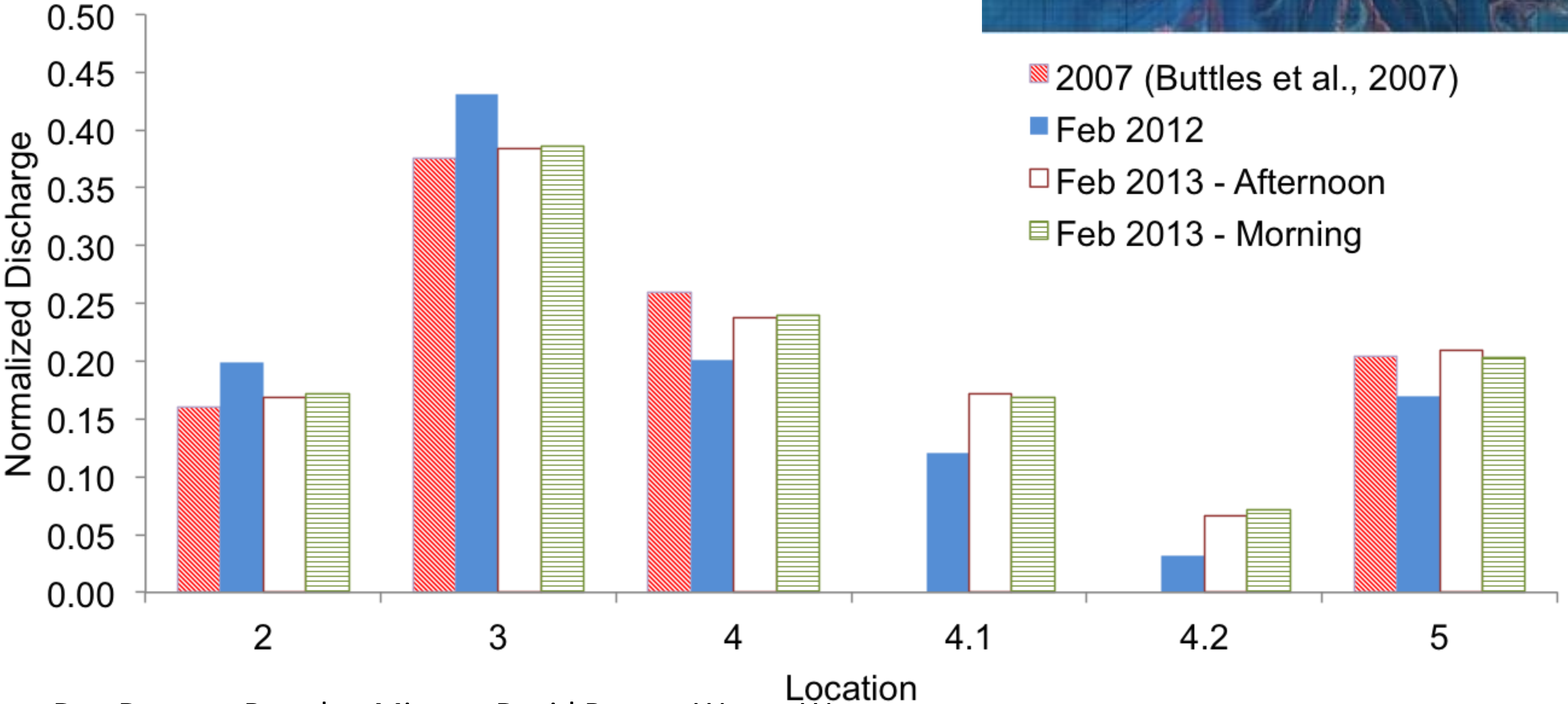
Flow partitioning among distributary channels



Flow partitioning at 4 major channels

Constant with time

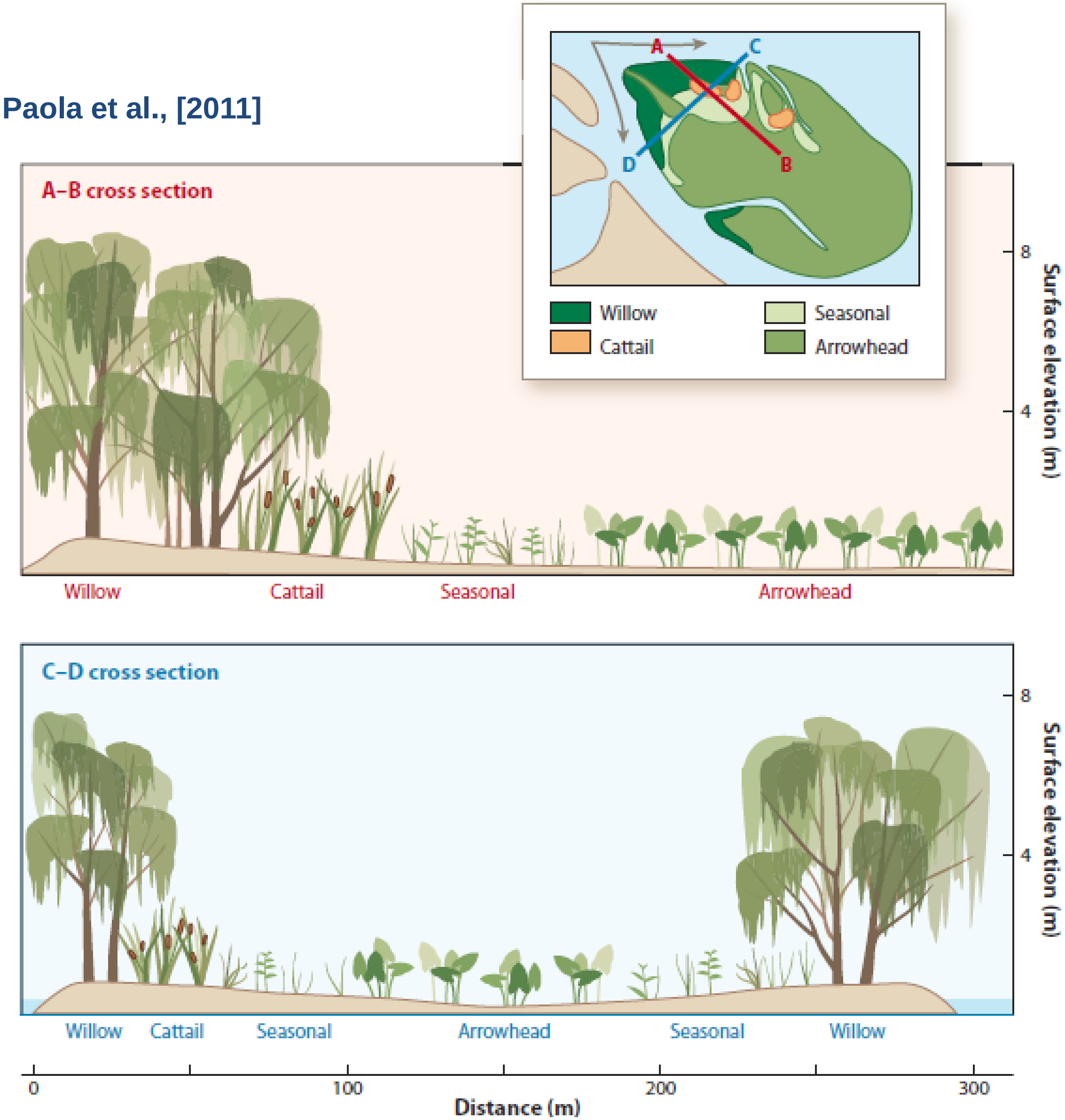




2013 Data: Dan Duncan, Brandon Minton, David Brown, Wayne Wagner

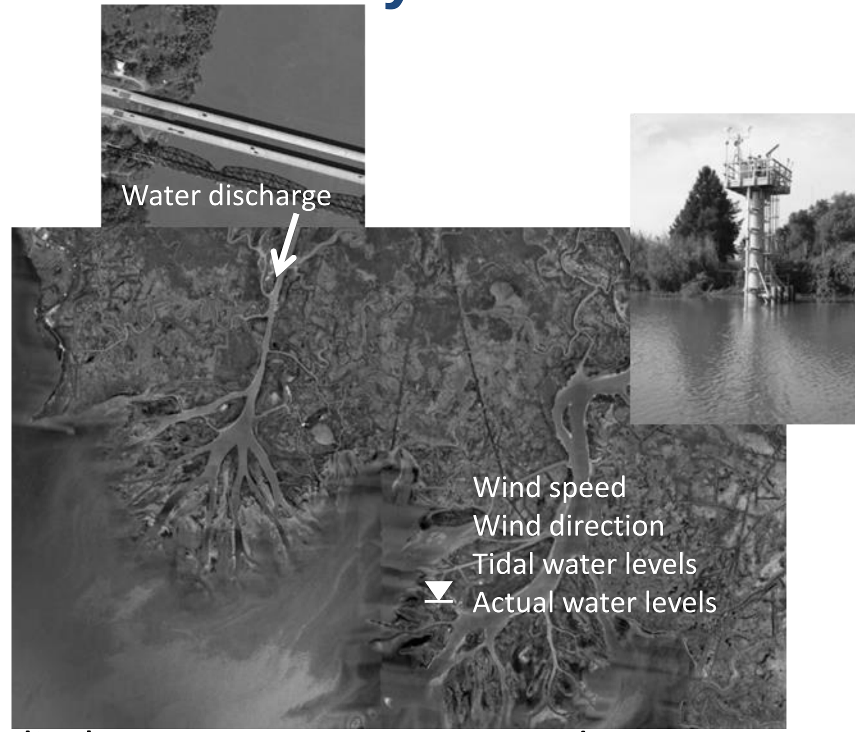
Delta channel and island connectivity and denitrification

Paola et al., [2011]

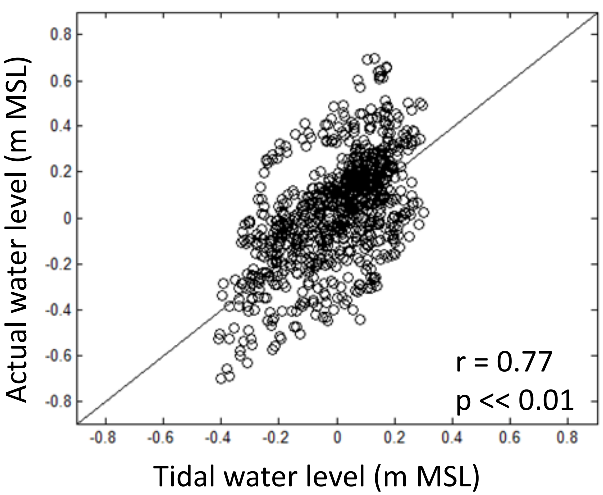


Environmental controls on shoreline dynamics

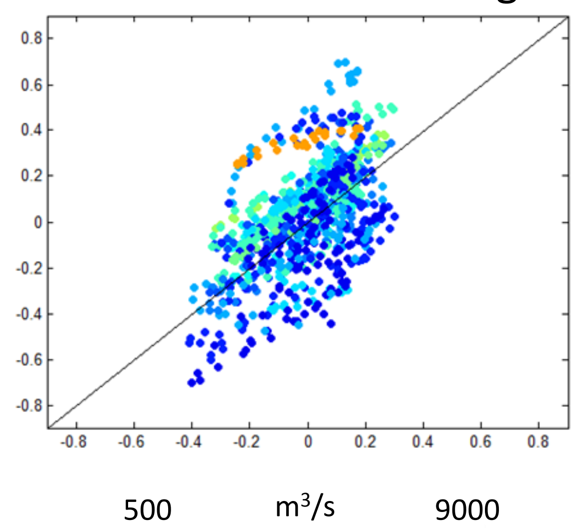
Step 1: understanding water level dynamics
Through: analysis hydro & wind data (NOAA)
(point measurements)



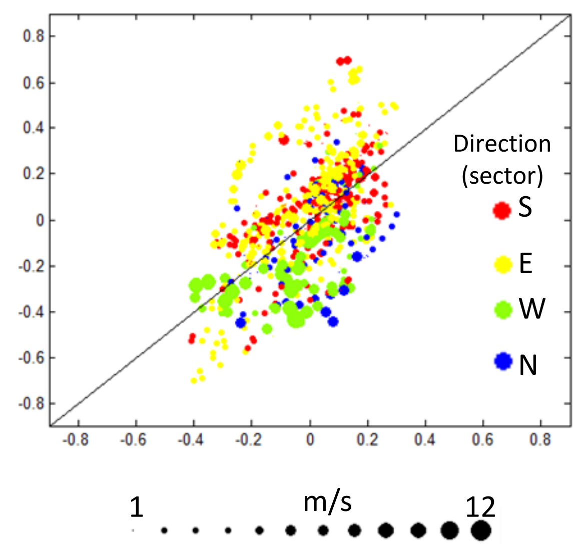
Tides



Riverine water discharge



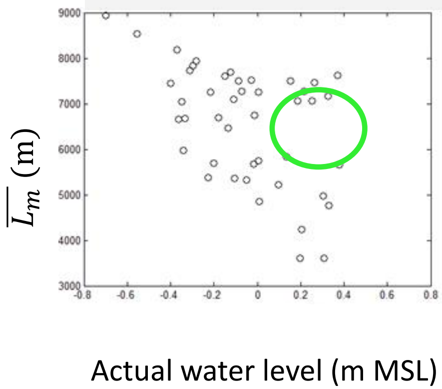
Wind

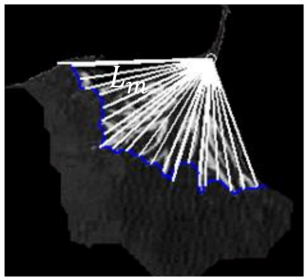


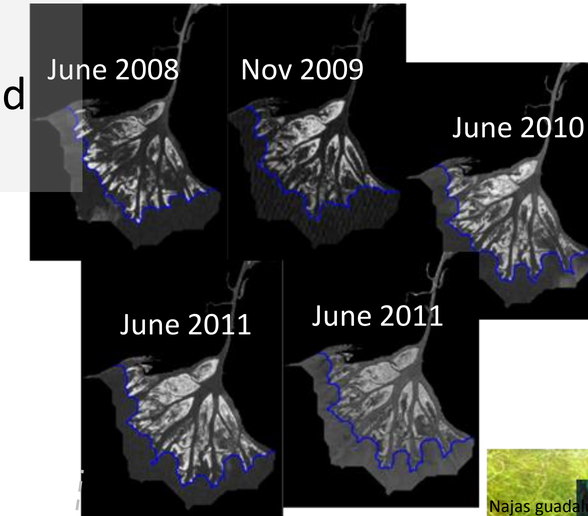
Geleynse, N., M. Hiatt, H. Sangireddy, and P. Passalacqua, in preparation.

Step 2: understanding shoreline dynamics

Through: landform extraction and interpretation of satellite imagery (NASA) (Results confirmed by Delft3D numerical modeling







Vegetation!