Linking Channel Dynamics to Deposits: How Does Process Understanding Change With the Scale of Observation?*

J.C. Rowland[1], W. Dietrich[2], M. Stacey[3], G. Hilley[4], A. Fildani[5], and E. Shele[1]

Search and Discovery Article #41675 (2015)**
Posted August 31, 2015

*Adapted from oral presentation given at AAPG 2015 Annual Convention and Exhibition, Denver, Colorado, May 31 – June 3, 2015

[1]Earth & Environmental Sciences, Los Alamos National Laboratory, Los Alamos, NM, USA (jrowland@lanl.gov)
[2]EPS, UC Berkeley, Berkeley, CA, USA
[3]C&EE, UC Berkeley, Berkeley, CA, USA
[4]GES, Stanford University, Stanford, CA, USA
[5]Statoil, Austin, TX, USA

Abstract

Linking stratigraphic and sedimentological attributes of depositional landforms to process dynamics is challenging due to the limited spatial and temporal scales over which measurements may be made relative to the scales that the landforms develop. Here we present process-oriented studies of river and submarine channel levee development, and of floodplain evolution conducted using vastly different scales of observation. Levee development studies were conducted in a laboratory basin on experimental channels a few centimeters deep, while the floodplain studies were conducted using globally available satellite imagery spanning decades. In the laboratory, very high spatial and temporal resolution measurements of jet and density current hydrodynamics and sediment transport were made and linked to patterns of deposition. While these process-based experiments are vastly simplified, relative to natural systems, they provided fundamental insights into the conditions necessary for levee formation at the distal ends of rivers and submarine channels. These insights have served to elucidate how balances in lateral sediment transport and jet dynamics govern deltaic channel formation and provided validation datasets for state of the art morphodynamic models. In submarine systems, the dynamics of density, flow spreading, and entrainment of ambient water critically constrain depositional patterns and highlight fundamental difference between submarine and terrestrial systems despite common channel morphologies. Using multi-temporal satellite imagery, we measured of river planform change and floodplain development on rivers systems across the globe. These measurements allow us to use natural systems as experimental realizations from a broad range of settings. This large-scale study of floodplain systems does not provide direct measurements of hydrodynamic and morphodynamics controls, but does provide the opportunity to relate variations in the rate of planform change to other measurable attributes of river systems such as: size, discharge, drainage area, slope, sediment supply and character, climate, and vegetation. These coupled measurements help to isolate the dominant watershed-scale controls on floodplain development and motivate hypotheses on the dominant controls on river mobility. This type of study also has the potential to provide empirical parameterizations for system scale modeling of sedimentology and earth system dynamics.

References Cited

Covault, J.A., 2011, Submarine fans and canyon-channel systems; a review of processes, products, and models: Nature Education Knowledge, v. 1/12, Web Accessed August 21, 2015, http://www.nature.com/scitable/knowledge/library/submarine-fans-and-canyon-channel-systems-a-24178428.

Fagherazzi, S., D.A. Edmonds, W. Nardin, N. Leonardi, A. Canestrelli, F. Falcini, D. Jerolmack, G. Mariotti, J.C. Rowland, and R.L. Slingerland, 2015, Dynamics of River Mouth Deposits: Rev. Geophys., v. 53, doi:10.1002/2014RG000451.

Findani, A., S.M. Hubbard, J.A. Covault, K.L. Maier, B.W. Romans, M. Traer, and J.C. Rowland, 2012, Erosion at inception of deep-sea channels: Marine and Petroleum Geology, v. 41, p. 48-61, Web Accessed August 21, 2015, http://www.vtsedsystems.org/wp-content/uploads/2012/05/2013-Fildani-etal-inception-of-deep-sea-channels.pdf.

Mariotti, G., F. Falcini, N. Geleynse, M. Guala, T. Sun, and S. Fagherazzi, 2013, Sediment eddy diffusivity in meandering turbulent jets: Implications for levee formation at river mouths: J. Geophys. Res. Earth Surf., v. 118, p. 1908–1920, doi:10.1002/jgrf.20134.

Mohrig D., and J. Buttles, 2007, Deep turbidity currents in shallow channels: Geology, v. 35, p. 155-158, doi: 10.1130/G22716A.

Normark, W. R., 1970, Growth patterns of deep-sea fans: AAPG Bulletin, v. 54, p. 2170-2195.

Posamentier, H.W., and V. Kolla, 2003, Seismic Geomorphology and Stratigraphy of Depositional Elements in Deep-Water Settings: Journal of Sedimentary Research, v. 73/3, p. 367-388.

Rowland, J.C., W.E. Dietrich, and M.T. Stacey, 2010, Morphodynamics of subaqueous levee formation: Insights into river mouth morphologies arising from experiments: J. Geophys. Res., v. 115, F04007, doi:10.1029/2010JF001684.

Straub, K.M., and D. Mohrig, 2008, Quantifying the morphology and growth of levees in aggrading submarine channels: Journal of Geophysical Research – Earth Surface, v. 113/F3, F03012, doi: 10.1029/2007JF000896.

Linking Channel Dynamics to Deposits: How Does Process Understanding Change With the Scale of Observation?

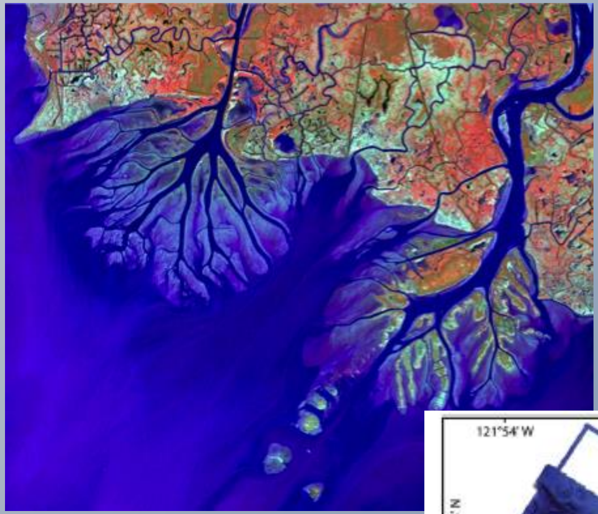
J. C. Rowland, W. Dietrich, M. Stacey, G. Hilley, A. Fildani, E. Shelef

Los Alamos National Laboratory,

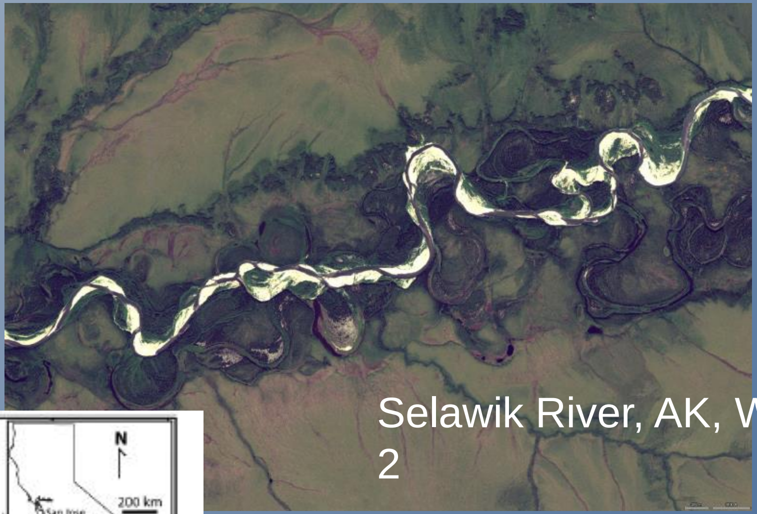
UC Berkeley, Stanford University, and Statoil

Los Alamos NATIONAL LABORATORY EST. 1943

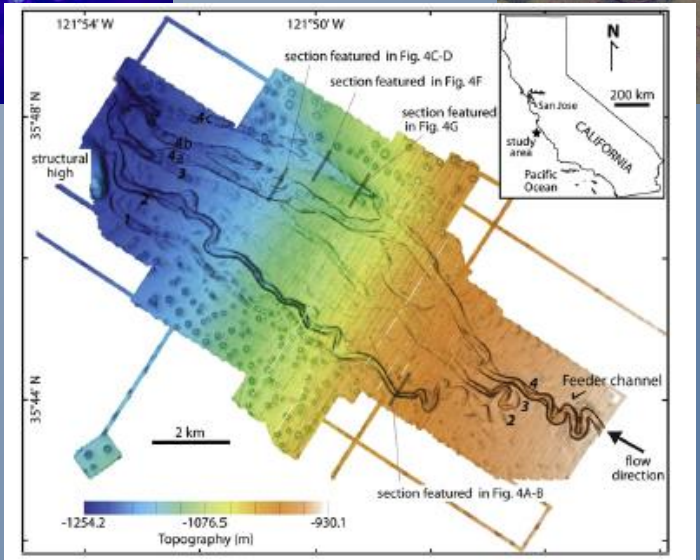
How do we bridge the gap between the scale we can measure and the ones we care about for system level understanding?



Atchafalaya Bay, Louisiana



Selawik River, AK, Worldv
2

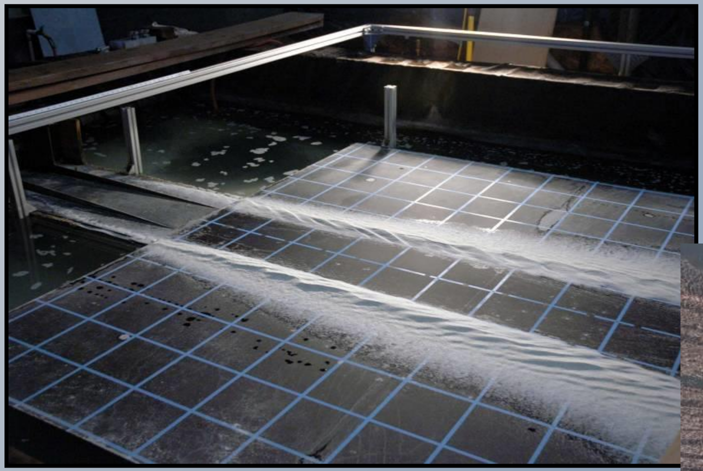


Fildani et al. 2012

Three research examples with measurement scales ranging from millimeters to 100s km

1) Experimental studies of fluvial levee formation at tie channels and river mouths
2) Experimental studies of submarine channel dynamics at sharp flow unconfinement transitions
3) Remote sensing analysis of planform river dynamics and floodplain exchanges

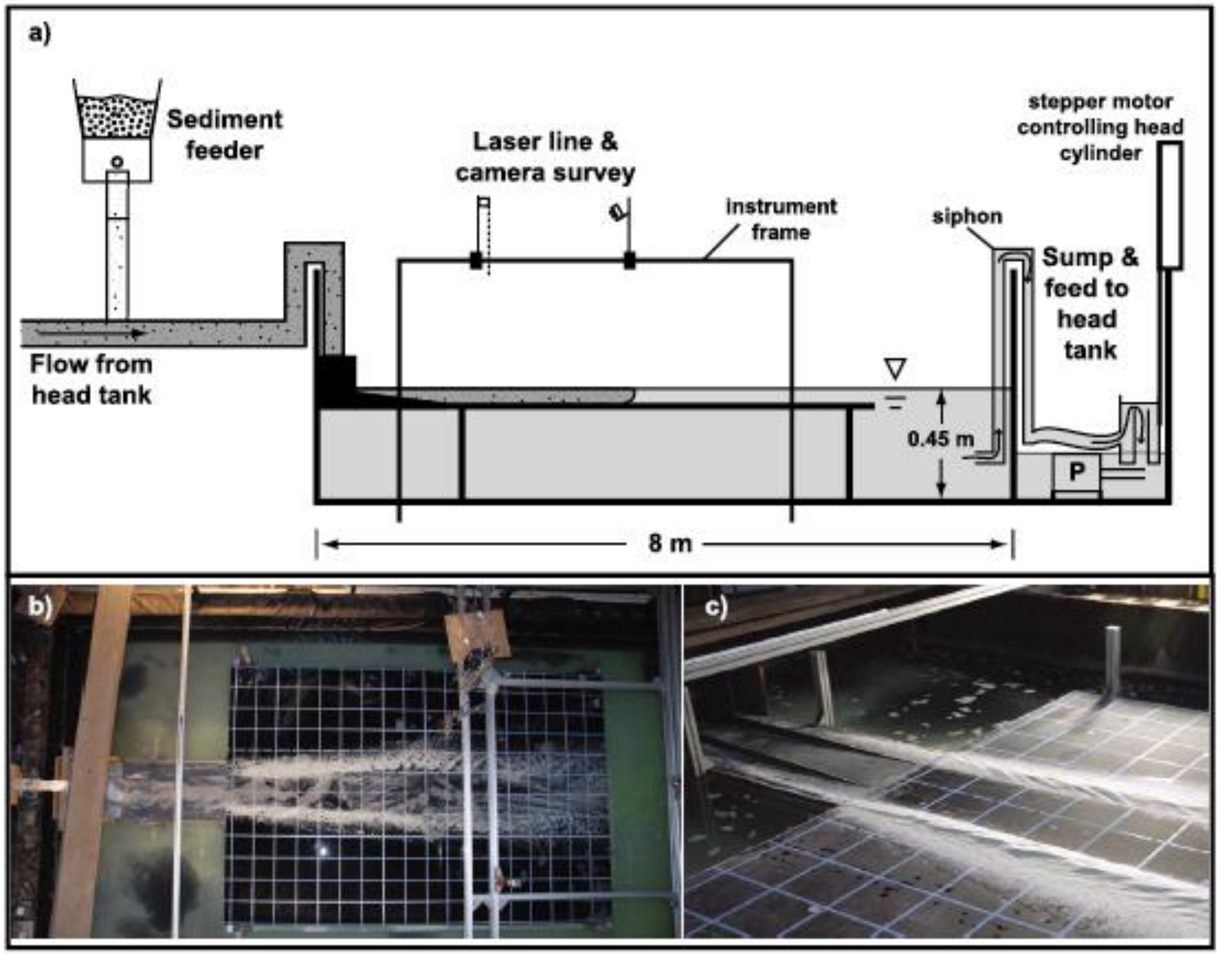
Case study 1: Fluvial Levees - from lab to single channel to deltas



Raccourci Old River, Louisiana

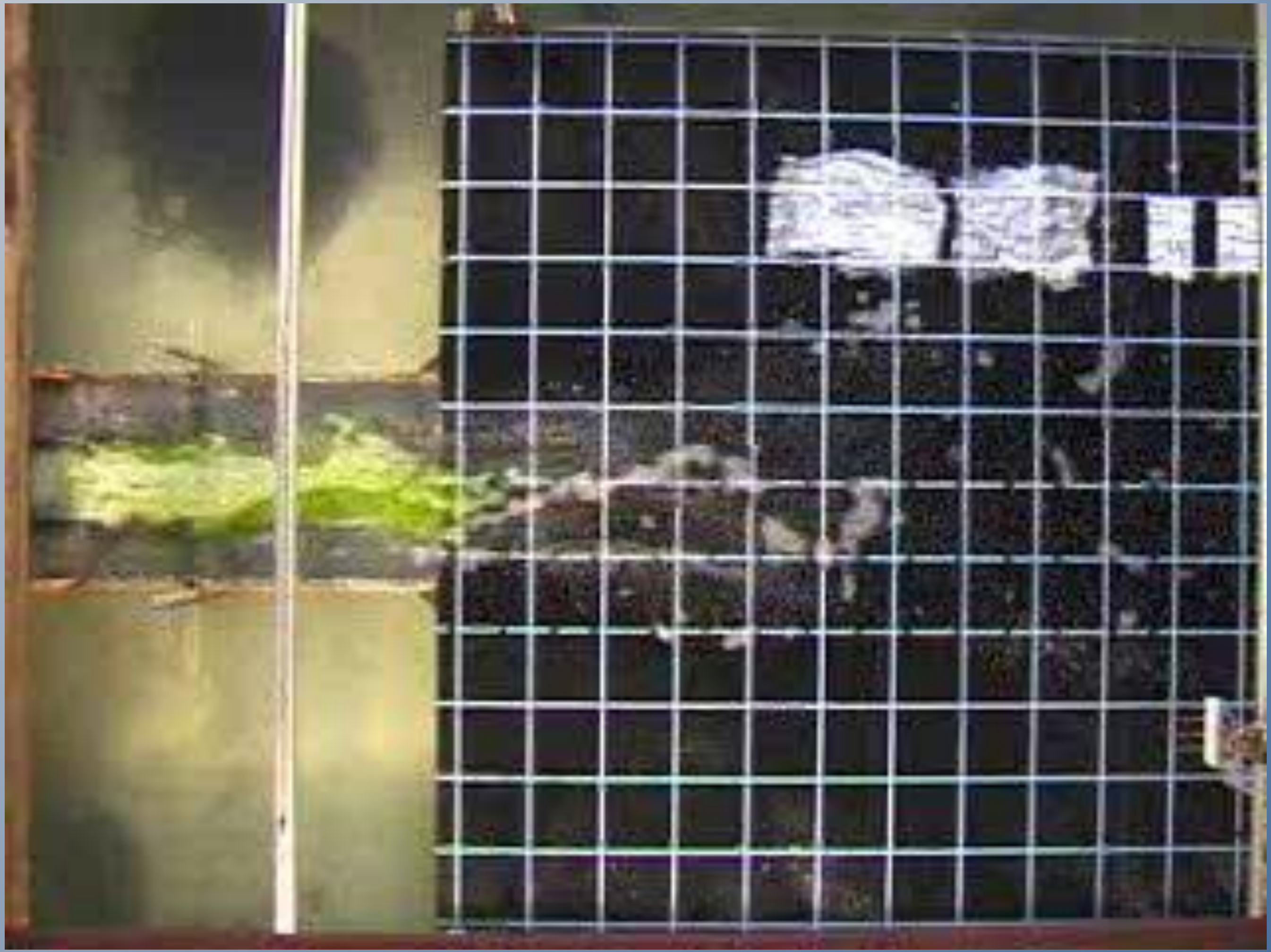
Atchafalaya Bay, Louisiana

Experimental setup

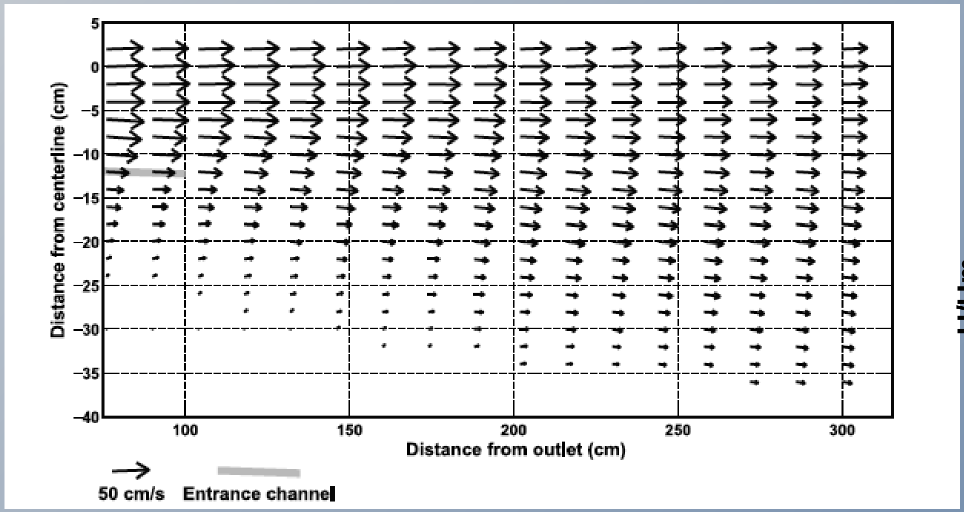


Rowland et al. 2010

Jet dynamics, large-scale flow instabilities, and levee formation

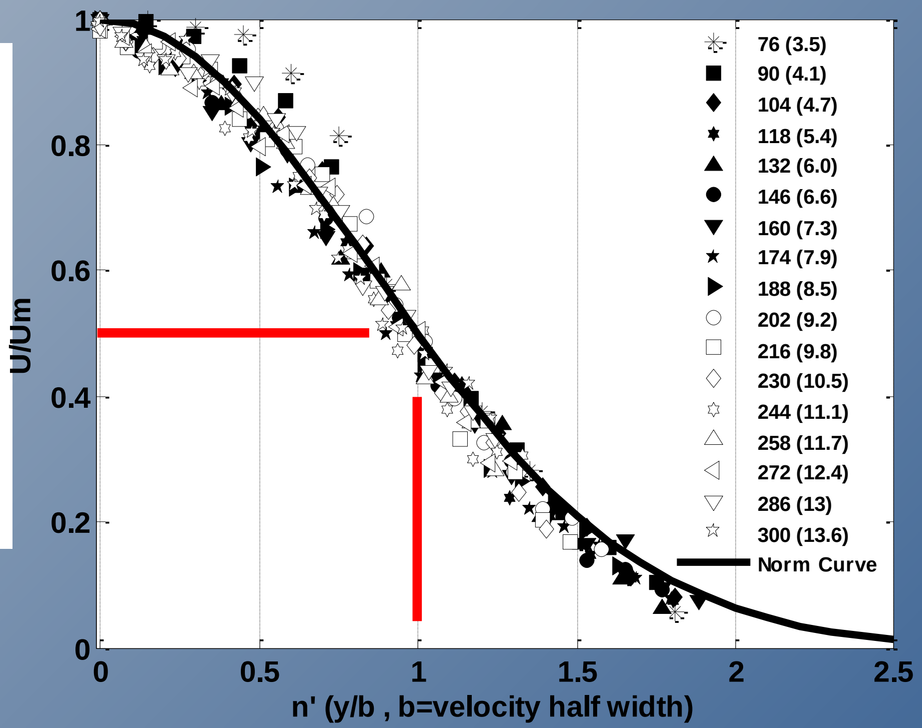


Time-averaged velocity field fit 'classic' self-similarity profiles for a turbulent jet



Rowland et al. 2010

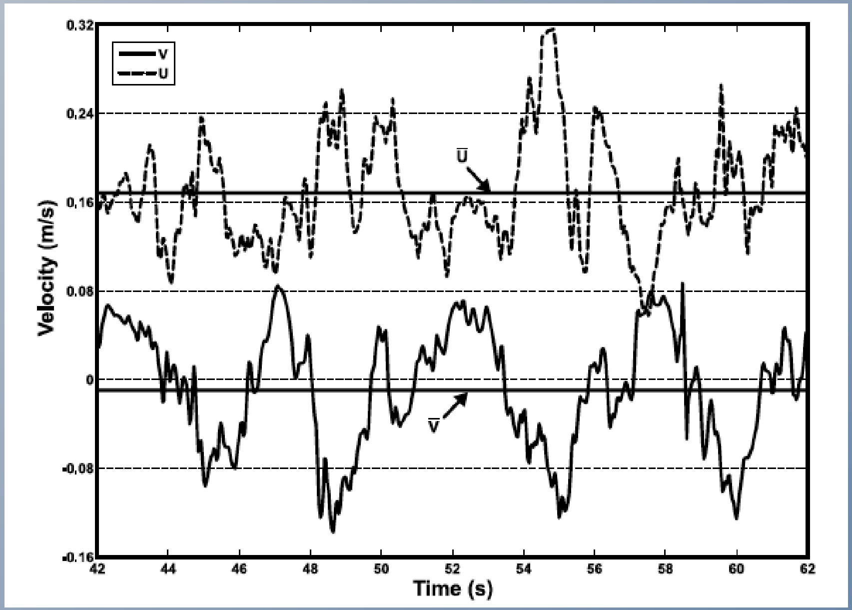
Normalized Velocity Distribution in Cross Stream

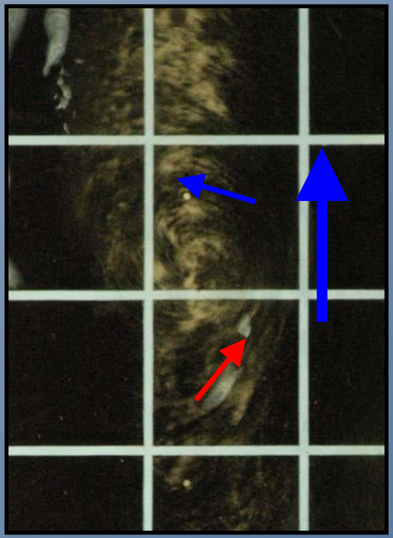


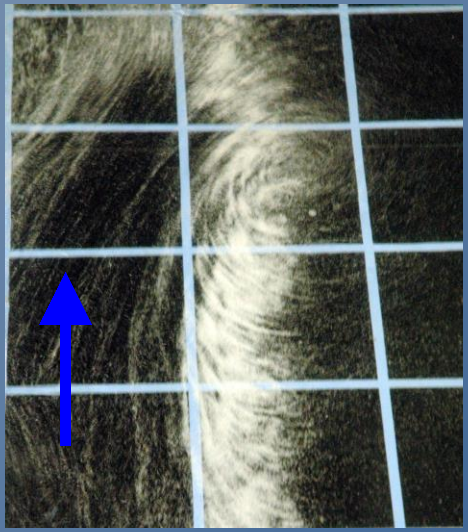
Velocity ½ Width – U/Um=0.5 at a given X

Time-averaged velocity field is not what delivers the sediment to the flow margins

- **Parameterized sediment transport by modifying the lateral diffusivity to account for enhance advective transport**
- **Hypothesized the magnitude of lateral sediment diffusivity was a controls by the timescale of the meanders and the settling velocity of the sediment**

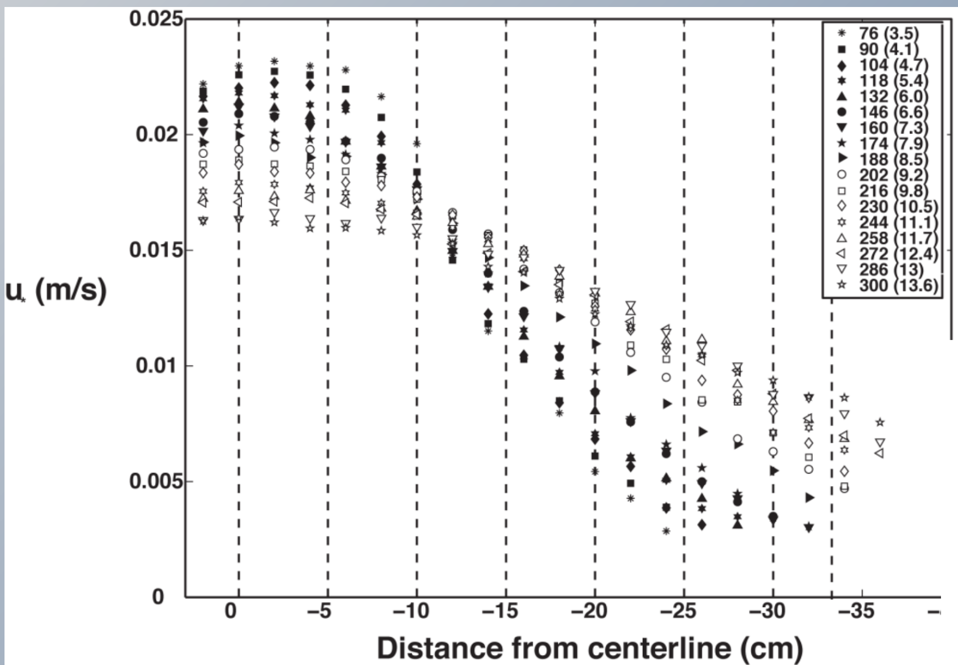




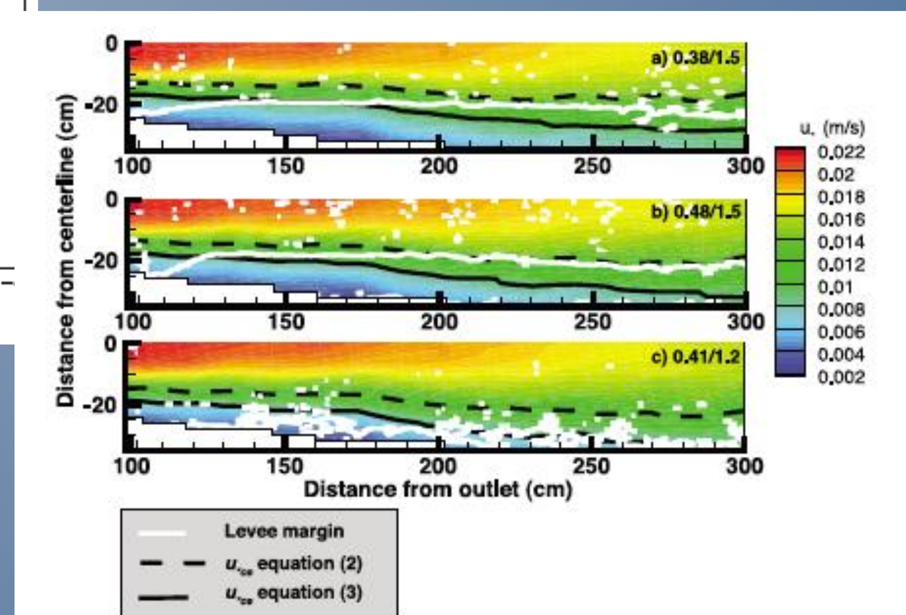


Rowland et al. 2010

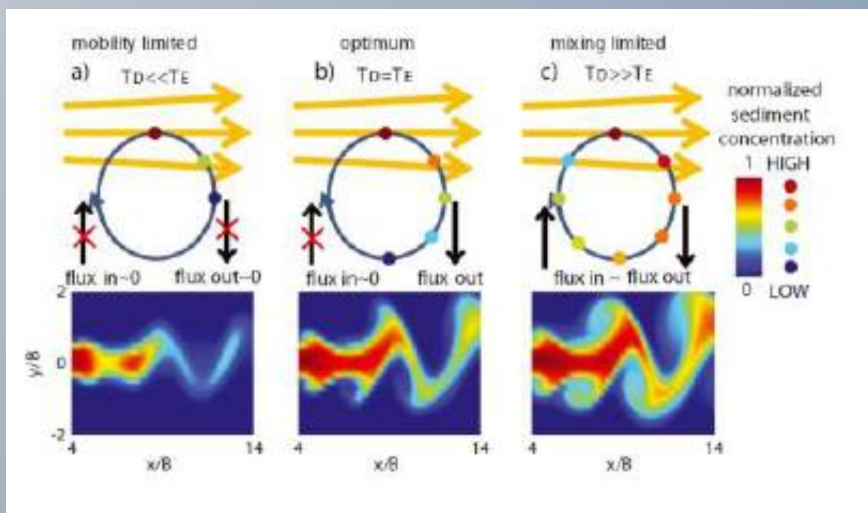
Determined the effective bed shear stress by incorporating fluctuating components of the streamwise and cross stream velocity



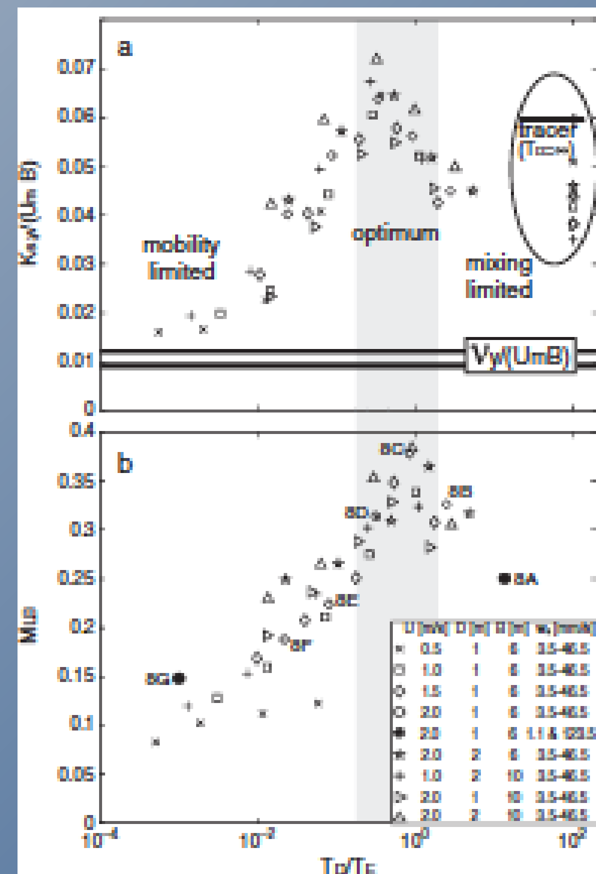
Rowland et al. 2010



Subsequent computer simulations have allowed a more expansive exploration of parameter space and helped define ‘optimal’ conditions for levee growth

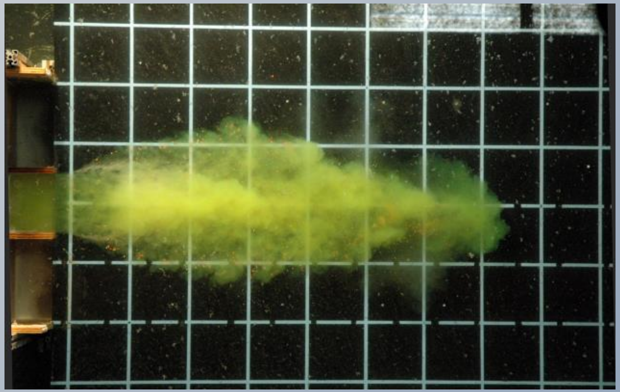


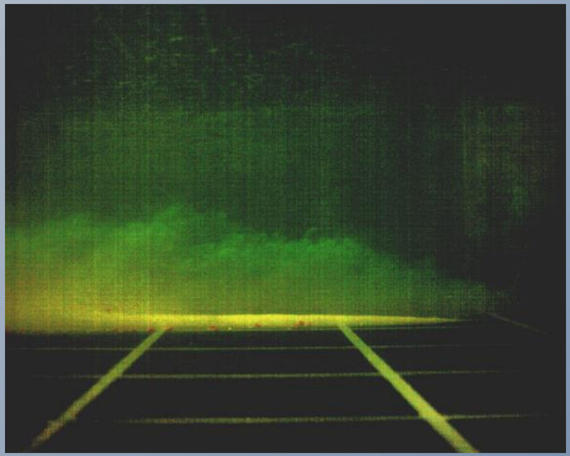
Mariotti, G., F. Falcini, N. Geleynse, M. Guala, T. Sun, and S. Fagherazzi (2013), Sediment eddy diffusivity in meandering turbulent jets: Implications for levee formation at river mouths, J. Geophys. Res. Earth Surf., 118, 1908–1920, doi:10.1002/jgrf.20134.



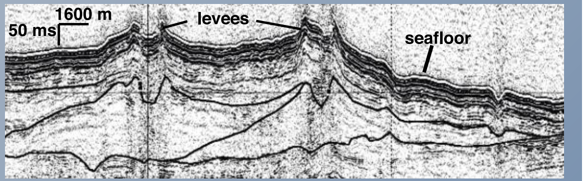
Also see: F*agherazzi, S., D. A. Edmonds, W. Nardin, N. Leonardi, A. Canestrelli, F. Falcini, D. Jerolmack, G. Mariotti, J. C. Rowland, and R. L. Slingerland (2015),* ***Dynamics of River Mouth Deposits****, Rev. Geophys., 53, doi:*[*10.1002/2014RG000451*](10.1002/2014RG000451)

Case study 2: Submarine Levees - from lab to levees to shelf systems

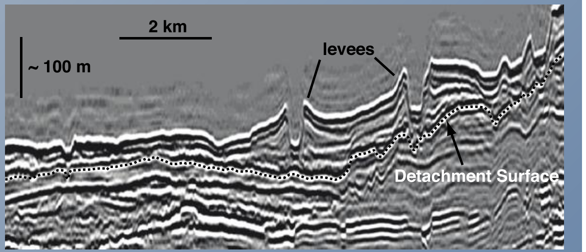




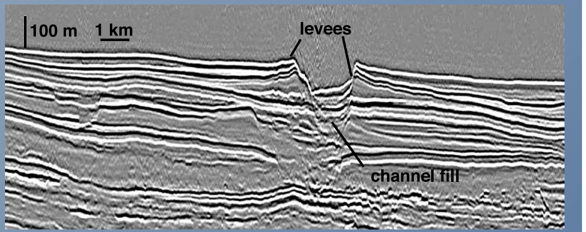
a) Mohrig and Buttles (2007)

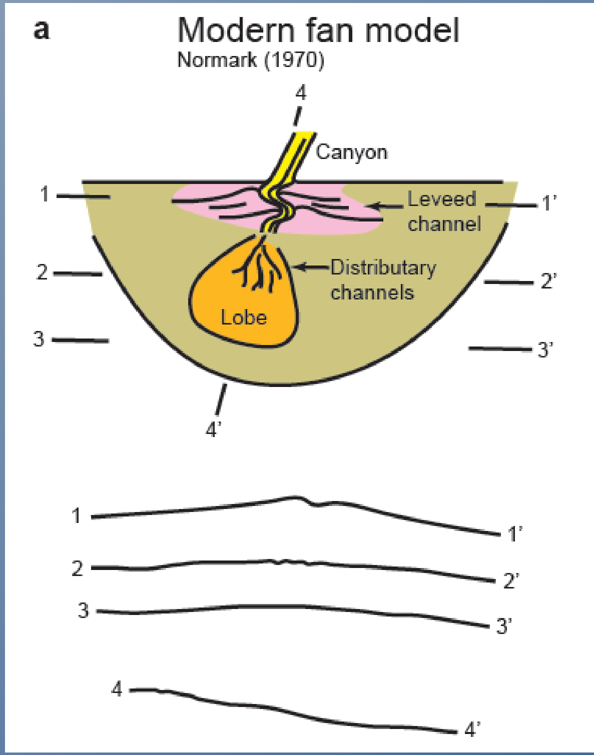


b) Straub and Mohrig (2008)



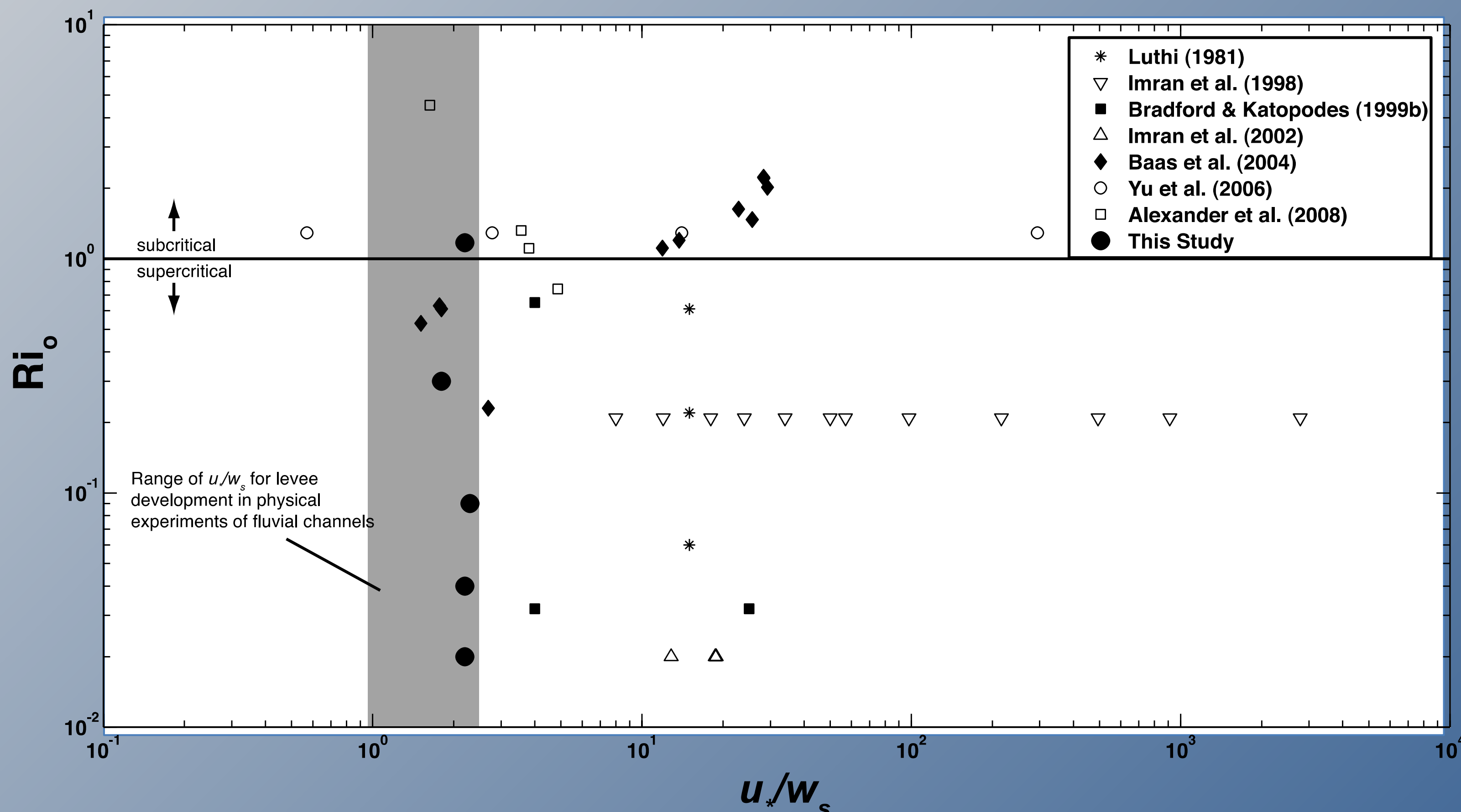
c) Posamentier and Kolla (2003)





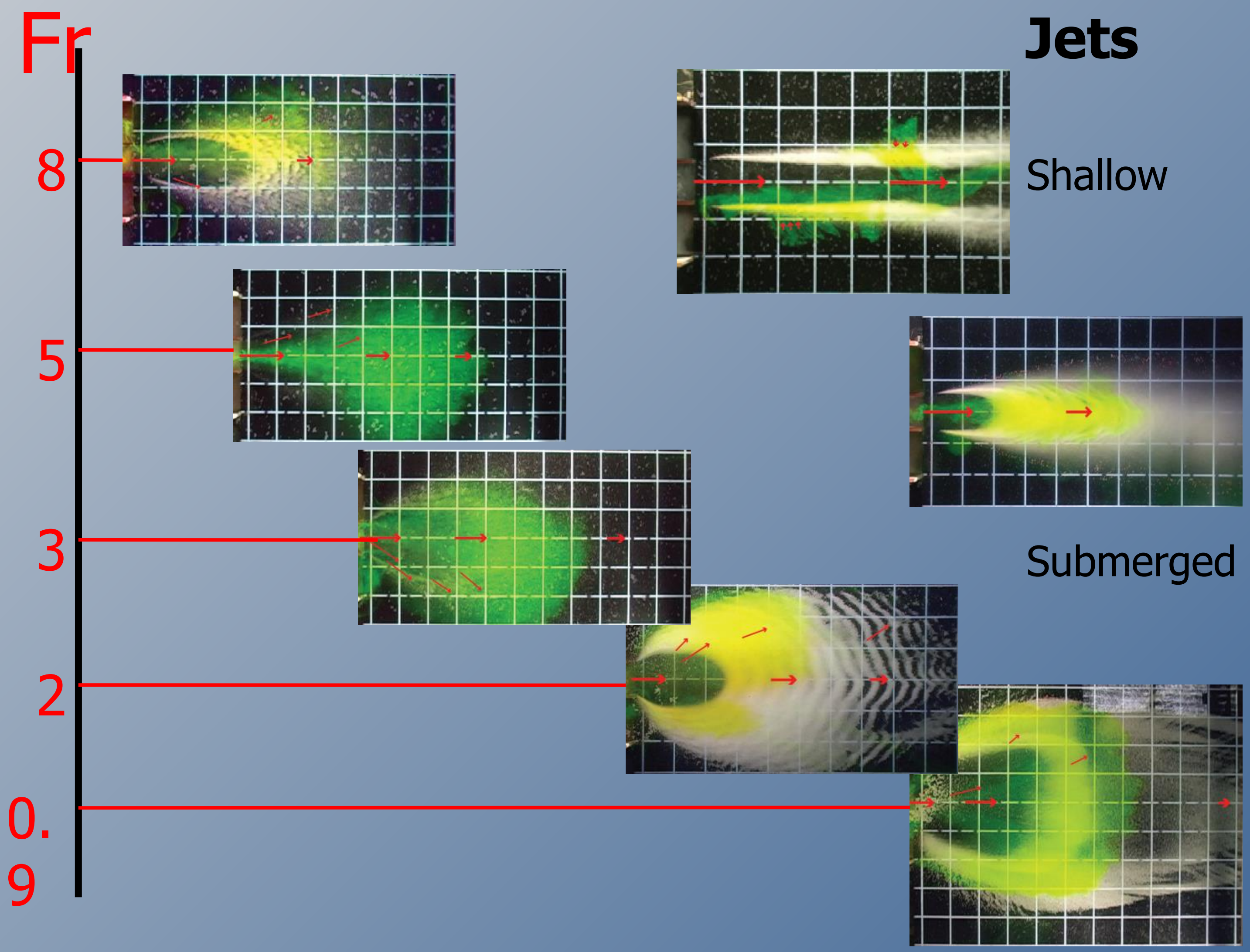
Covault (2011)

Do dynamics that govern fluvial levee development apply to submarine systems?

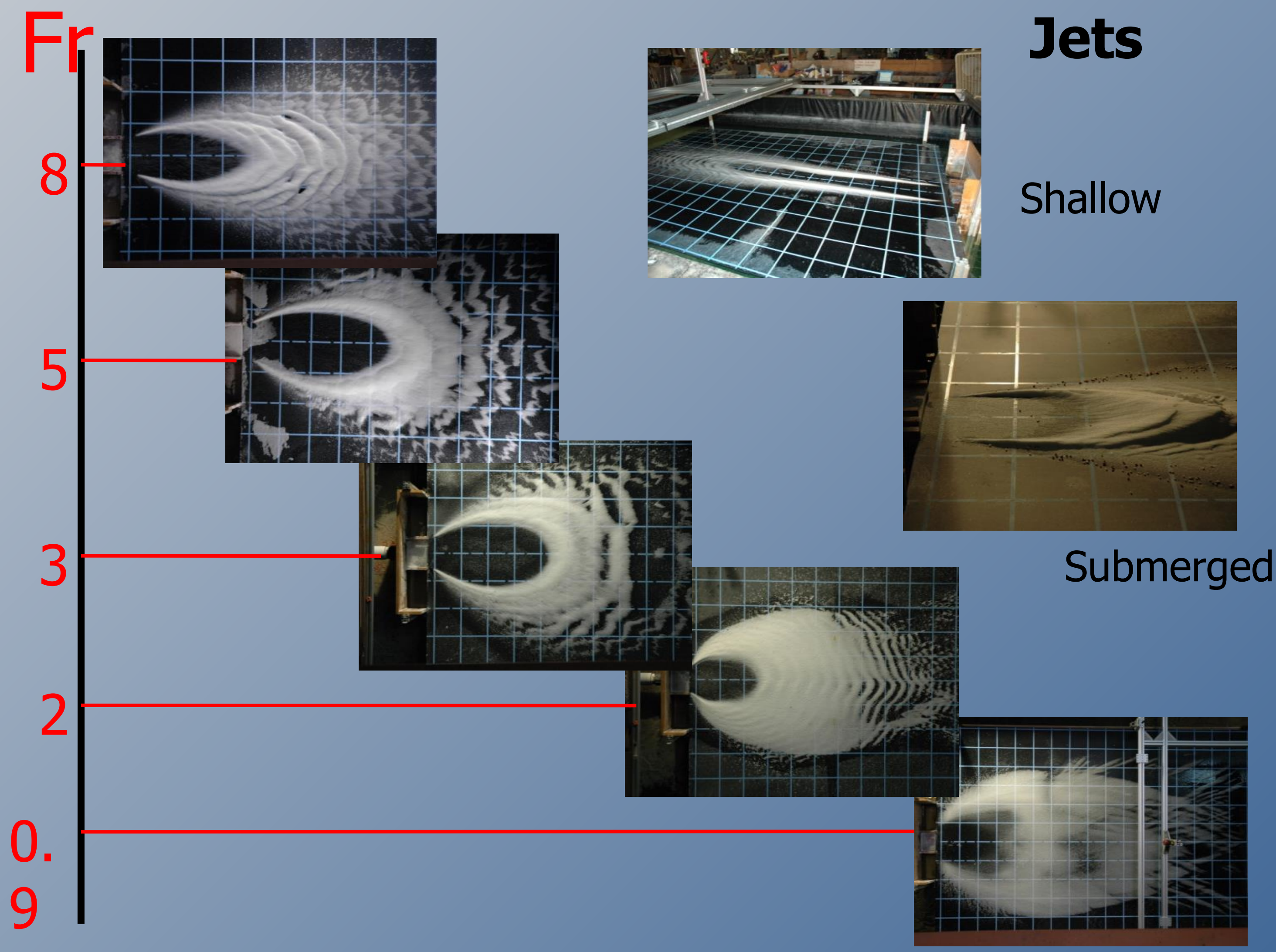


Rowland et al. 2010

Flow fields of density currents undergoing abrupt unconfinement

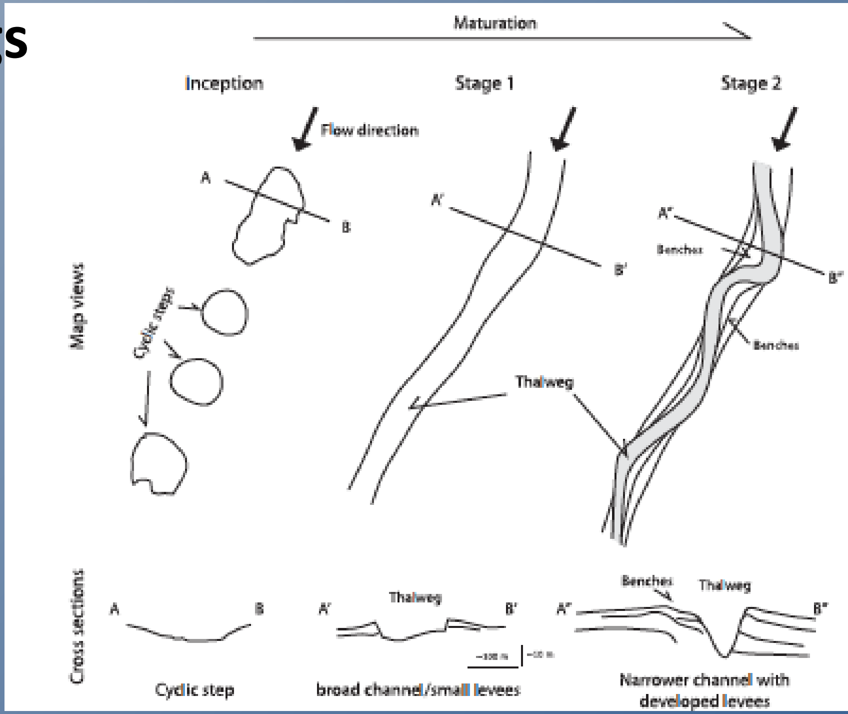


Deposits of density currents undergoing abrupt unconfinement



Experiments suggest we were lacking critical components of channel formation in experiments

- Hypothesized that partial confinement of current by bed erosion a necessary condition
- 1 mechanism may be cyclic steps eroding sea floor
- Recent fluvial studies suggest that this is also a common feature of river mouth settings



Fildani et al. 2012

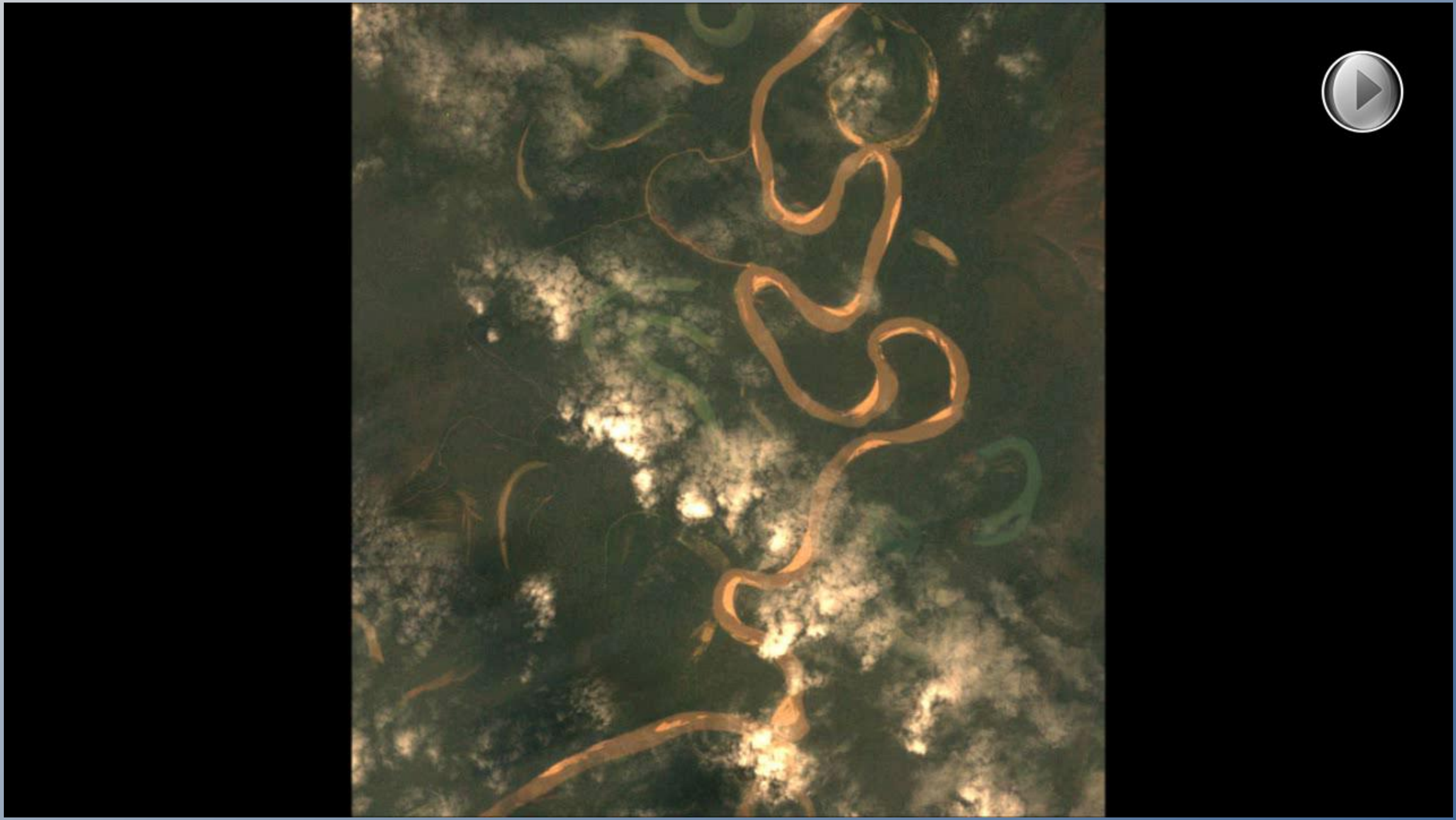
Case study 3: River bank dynamics – from floodplain to bend to bank scale

Strickland River, PNG

Selawik River, AK

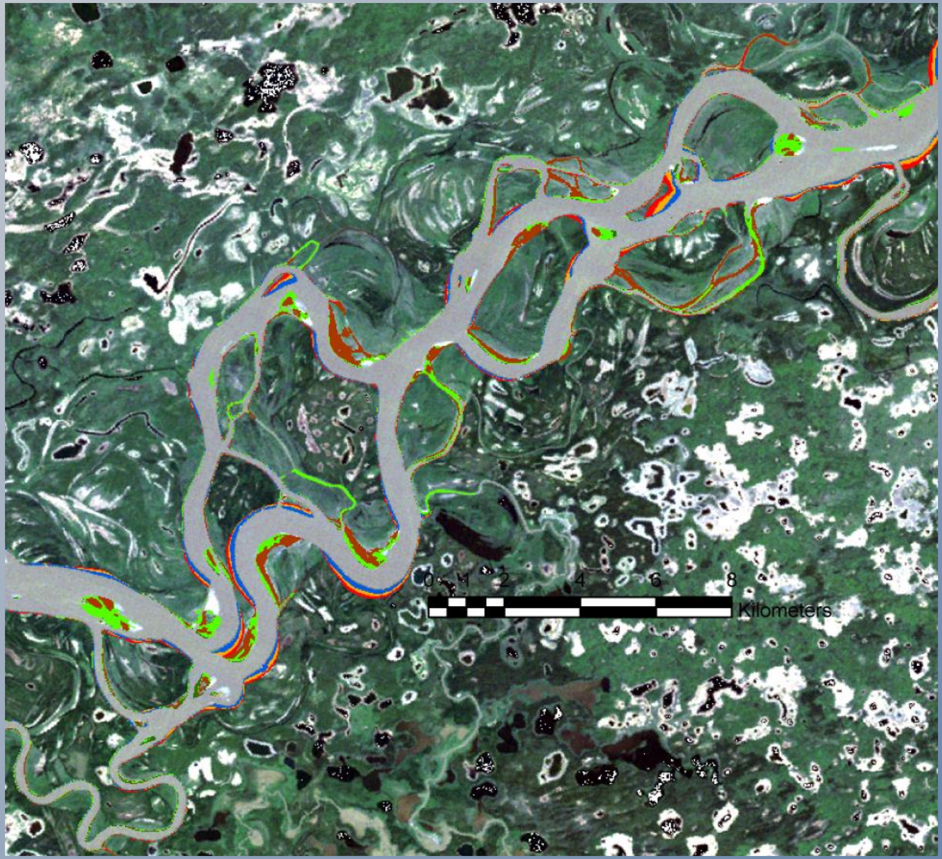
East River, CO

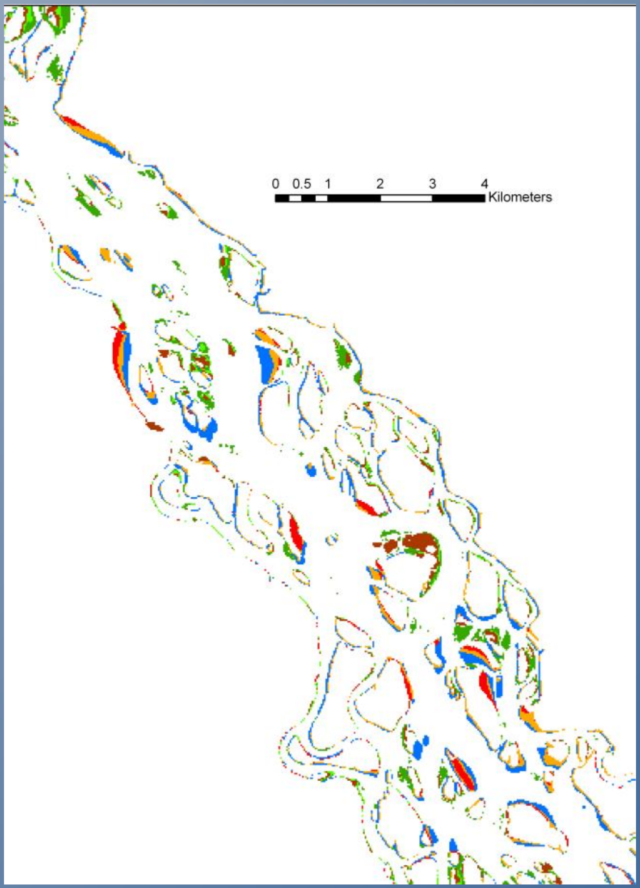
Experimental setup: Landsat and other remotely sensed imagery



Beni River, South America. Video courtesy of Alexandra Bryk, UC Berkeley, assembled with the Google Earth Engine

Extract river masks and compare spatial patterns and rates of change





Yukon River, AK

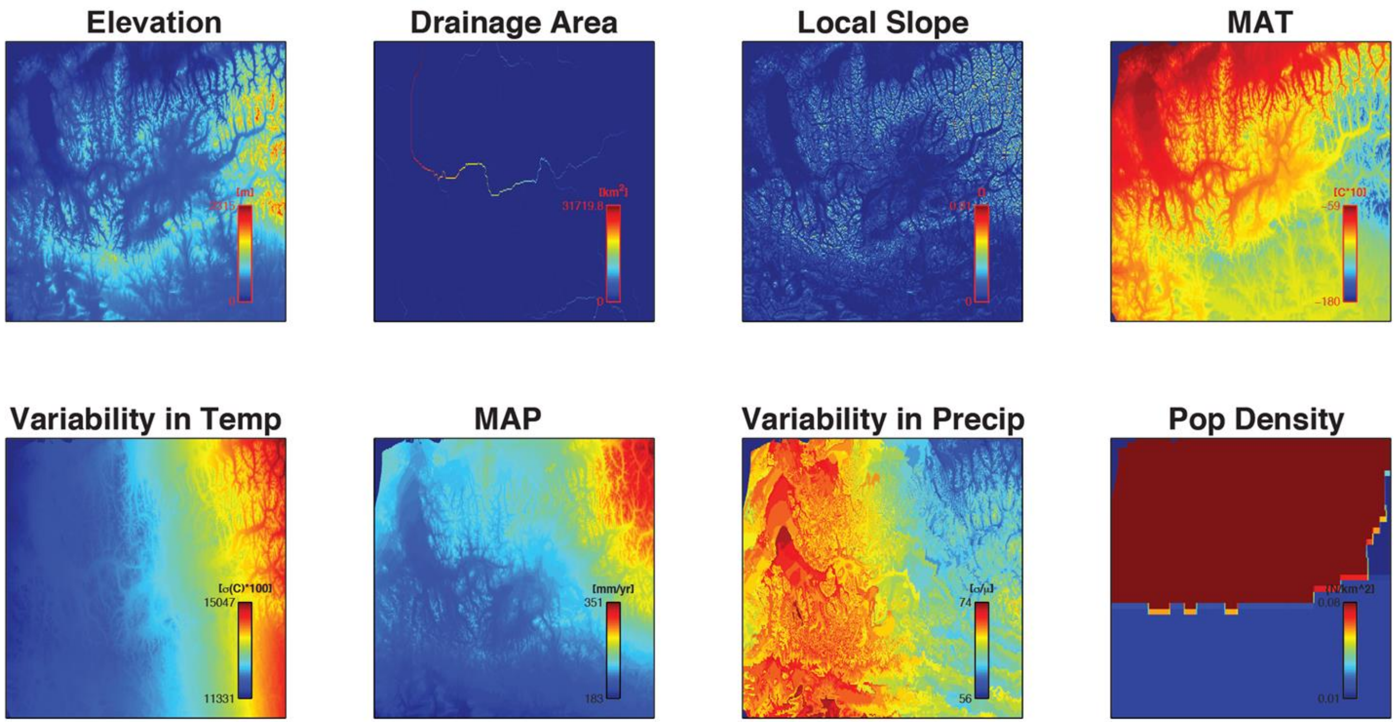
Use river masks to extract both local and reach scale metrics of river change and properties

- Measurements at every bank pixel:
  - Linear change rates
  - Channel width
  - Bank aspects
  - Curvature/Radius of Curvature

- At user defined intervals along river system referenced to a centerline:
  - Mean change rates
  - Mean width
  - Effective/Cumulative width
  - Total area of change: erosion and accretion
  - Total bank length for all banks and islands
  - Number and area of islands

Compare metrics to global datasets for potential controls

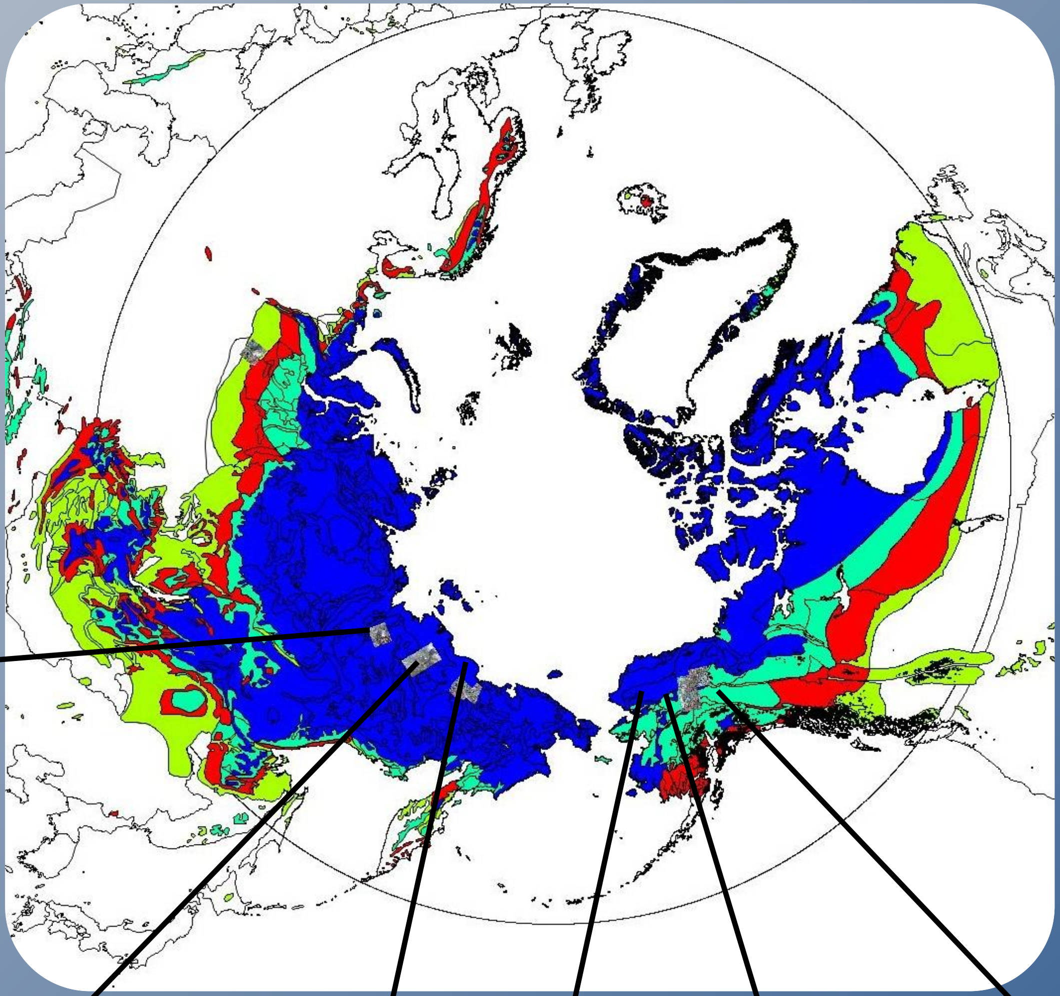
- Drainage area, topographic slope, basin relief, elevation, air temperature, variation in air temperature, precipitation, variability in precipitation, population density, soil density, percent gravel, sand, silt and clay in basin soils, soil organic carbon, and sediment yield.



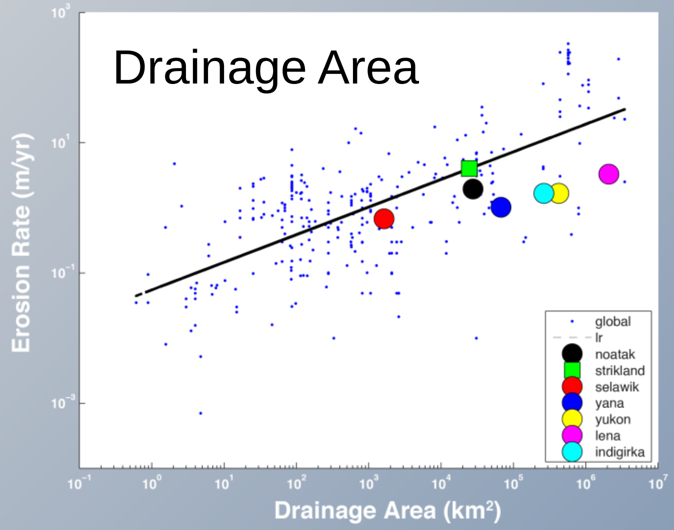
Starting analysis with high latitude watersheds

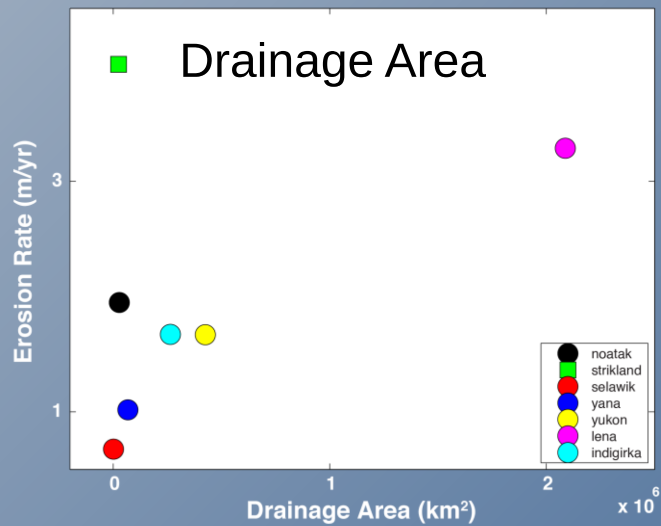
Permafrost Extent

- Continuous
- Discontinuous
- Sporadic
- Isolated



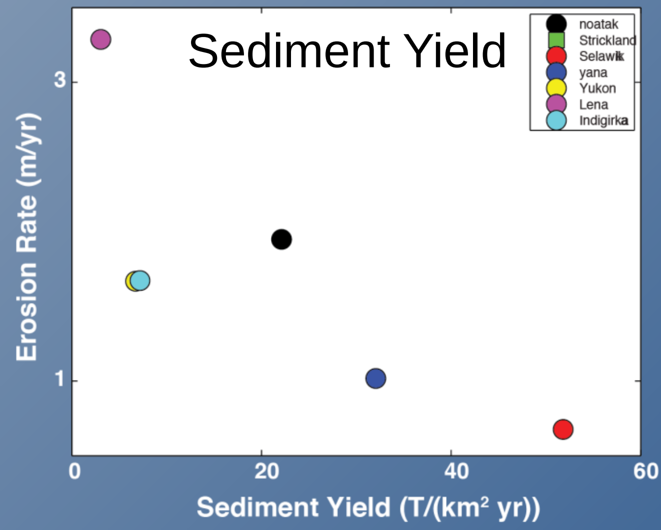
What controls river dynamics at scale of 10s to 100s of km?





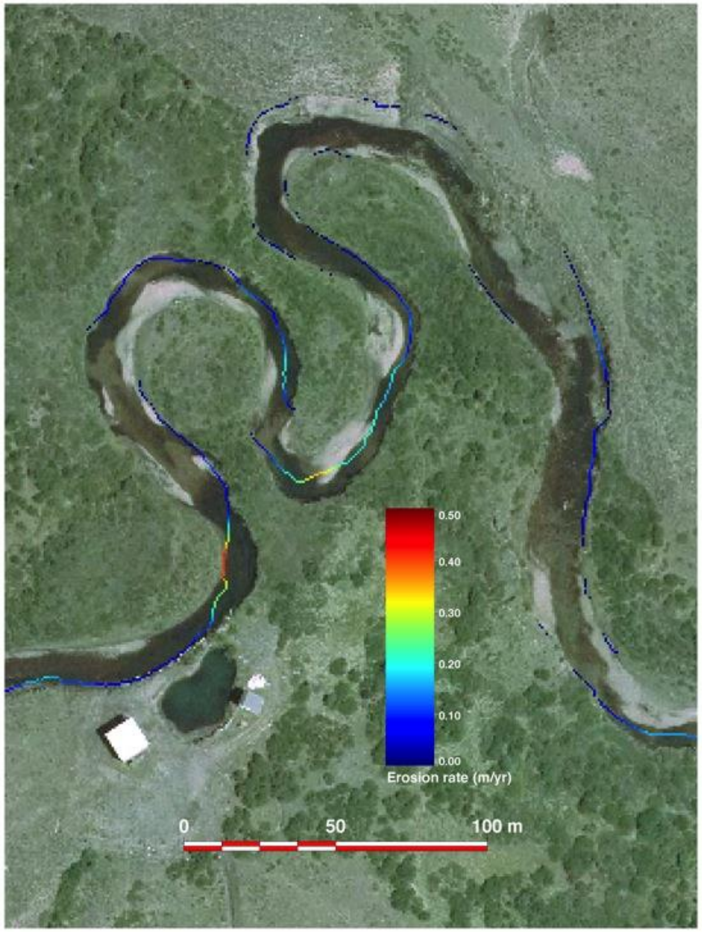
Length of analyzed reaches:

- Lena – 835 km
- Indigirka – 635 km
- Yukon – 380 km
- Strickland – 260 km
- Yana – 125 km
- Noatak – 50 km
- Selawik – 46 km

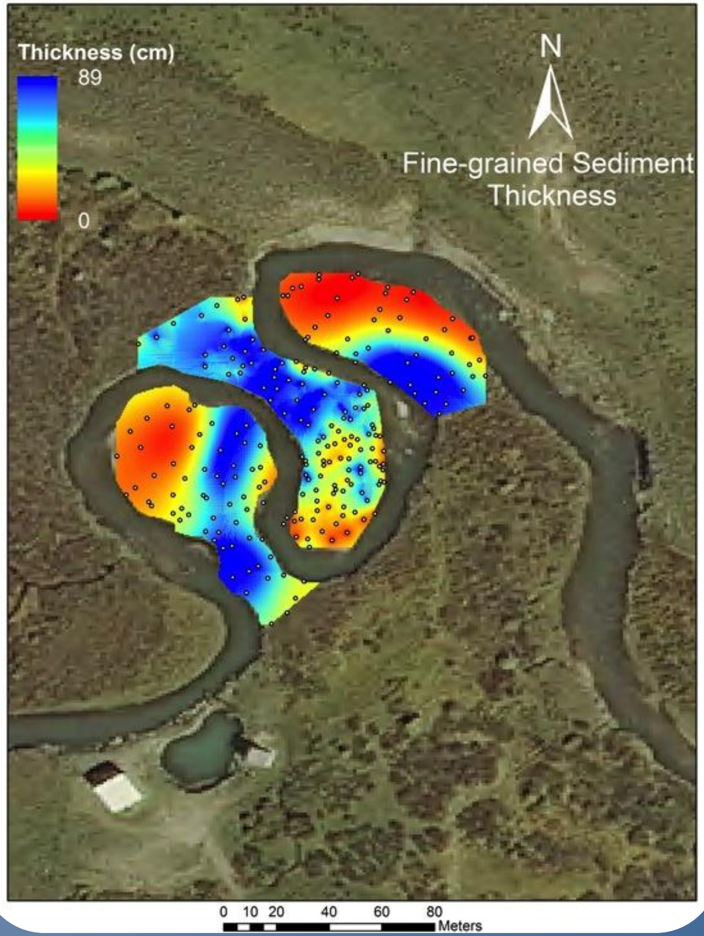


Rates and patterns of erosion at the sub-meter scale

Bank Erosion



Depth to gravel



Conclusions

- **Case 1: Fluvial levees process scaling appears to integrate understanding from centimeter scales up to full jet and river mouth scales. Numerical modeling suggest that process understanding extends to 10s of meters, but test of models has occurred at field scale and the effect of temporal variability in real systems is not captured in experiments or computer simulations**

Conclusions

- **Case 2: Relative effects of density versus entrainment and the impacts of flow spreading appears robust and suggests that process mechanics in submarine levee initiation are not analogous to fluvial systems. Additional controls on flow confinement and lateral deposition appears necessary**

Conclusions

- **Case 3: At the bank scale the process mechanics that control erosion and floodplain exchange appear similar across systems. When aggregated to the reach or river system scale we begin to see the effect of other controlling factors, such as bank strength and thermal controls. Different scales reveal the relative importance of different process controls and have the potential to offer unique insights.**

Acknowledgements

Funding for work includes:

- **American Chemical Society – Petroleum Research fund**
- **Chevron ETC**
- **National Center for Earth-Surface Dynamics**
- **Stanford University: Terman Fellowship**
- **Los Alamos National Laboratory – LDRD**
- **DOE Office of Science**

Integrated impact of local processes on floodplain exchanges and transfer offshore

- Back of the envelope calculations based on bank height estimates and deposit bulk densities give make a mass flux estimate