Modeling Floodplain Deposits*

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Search and Discovery Article #50628 (2012)**
Posted July 2, 2012

*Adapted from oral presentation at AAPG Annual Convention and Exhibition, Long Beach, California, USA, April 22-25, 2012.

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Abstract

Floodplain deposition maintains and builds up low-lying lands along rivers and on deltas. Over geological timescales, floodplain deposition and channel migration determine lowland depositional architecture with impacts on reservoir characteristics.

We advanced a 3D floodplain architecture model, AquaTellUs. AquaTellUs uses a nested model approach; a 2D longitudinal profile, embedded as a dynamical flowpath in a 3D grid-based space. We model the main channel belt as a 2D longitudinal profile that responds dynamically to changes in channel geometry, water discharge, sediment load, grain-size distribution and sea level based on first-order, physics-based principles. Sediment flux is described with a modified Exner equation by separate erosion and sedimentation components. Erosion flux along the main flowpath depends on river discharge and channel slope and is independent of grain-size. Depositional flux along the channel path as well as in the lateral direction into the floodplain depends on the local stream velocity, and on grain-dependent settling rates. Lateral depositional patterns are informed by analysis of remote-sensing imagery of recent flood deposits, particularly along the Indus River. Floodplain deposition is an event-driven system — only peak discharge events cause overbank flow, crevasse-splays, and potential channel avulsion. The computational architecture of AquaTellUs preserves stratigraphy by event, allowing for preservation of information of depositional layers of variable thickness and composition.

We present stratigraphic sections and pseudo-wells resulting from numerical experiments that show the pronounced effect of different probability density functions for river discharge and sediment load, i.e., flooding recurrence times on the stratigraphic architecture. These experiments generate training images and enhance reservoir geo-statistical modeling.

Selected References

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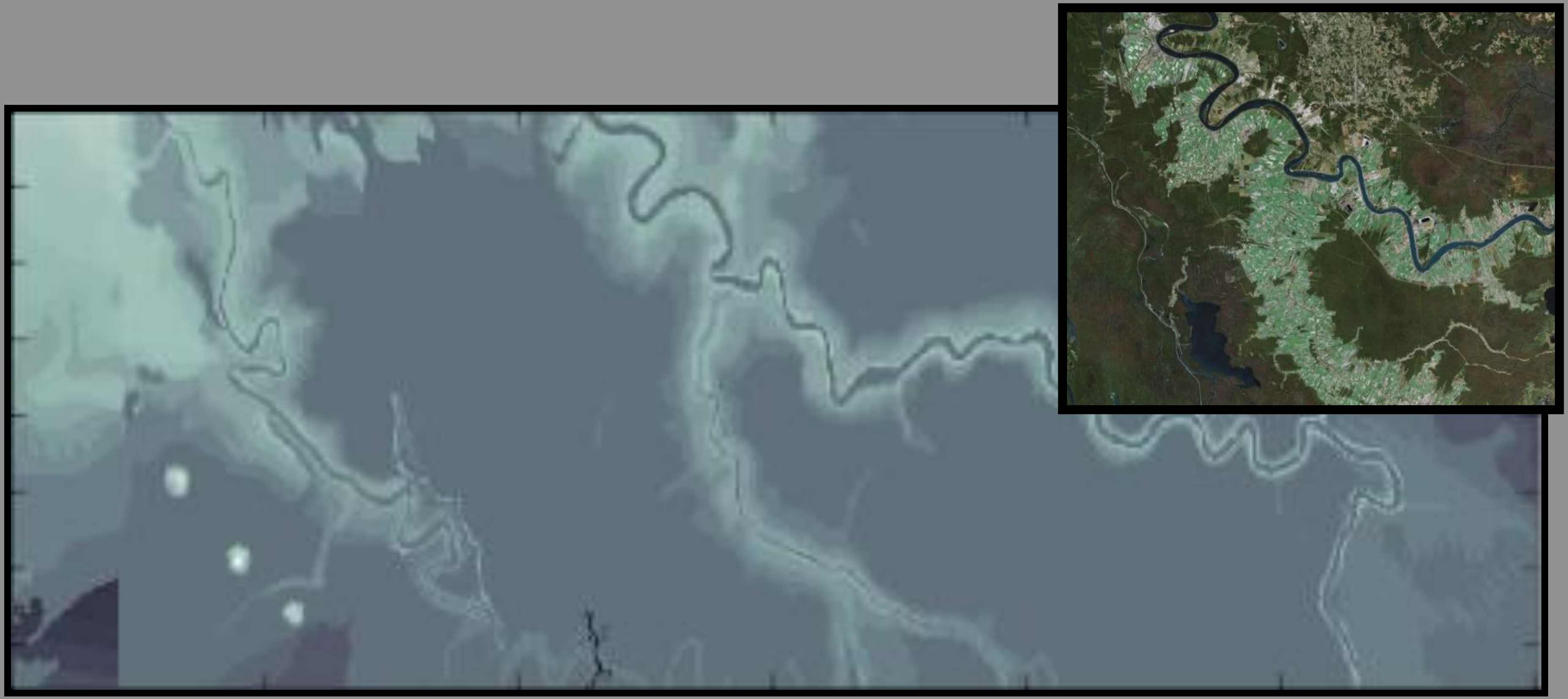
Modeling Floodplain Deposits



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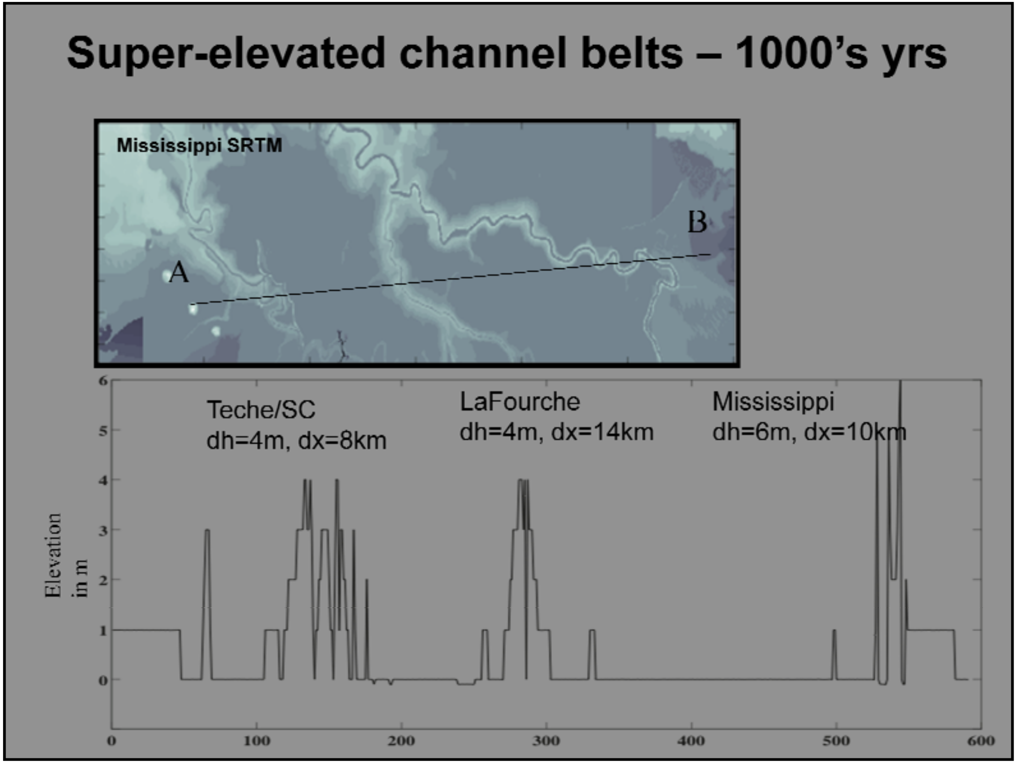
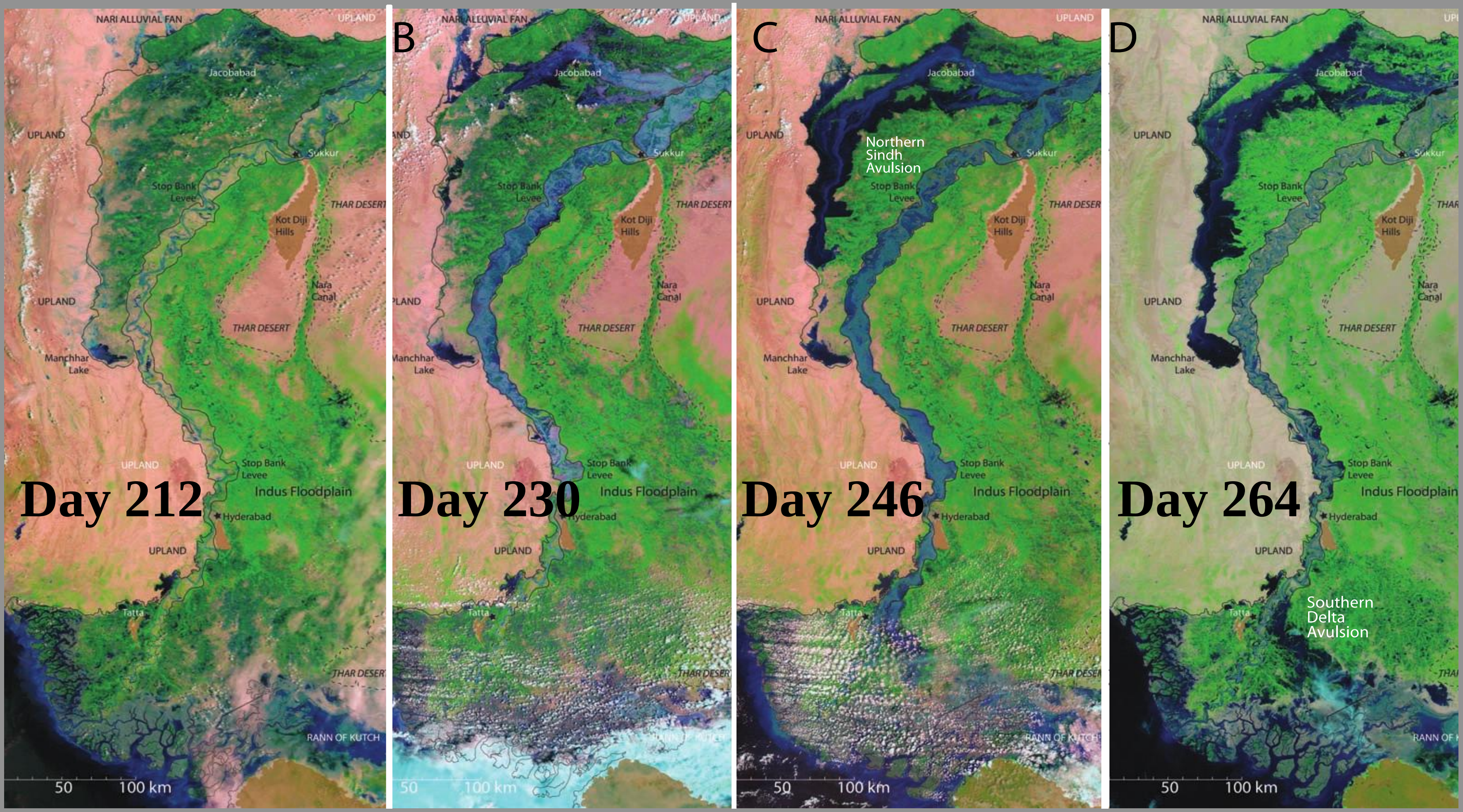
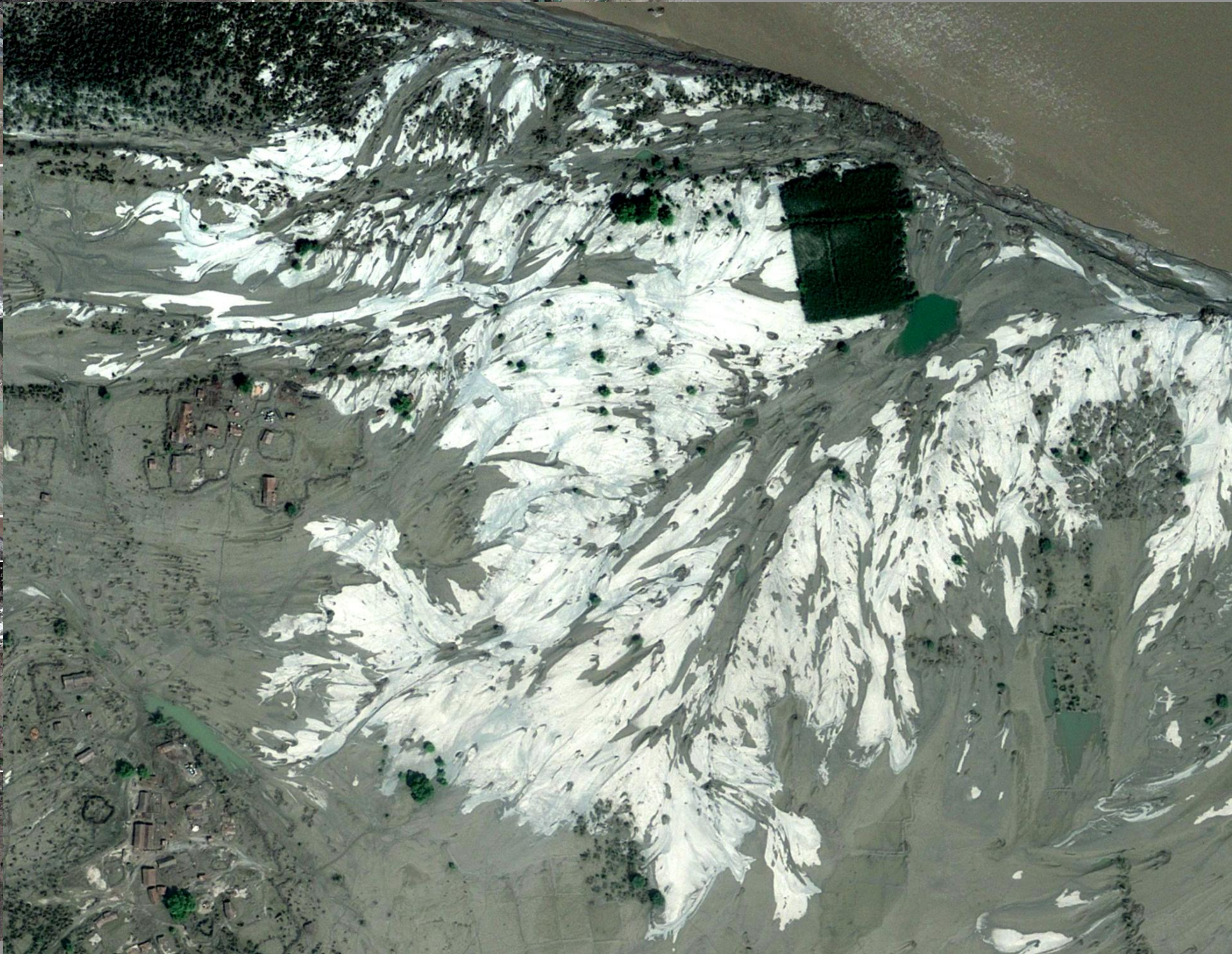


Presenter's notes: Teche lobe: 3500-2800 years ago; Sale –Cypremort lobes: 4600 years ago; Lafourche: 1000-3000 years ago. Focus of this presentation is on Holocene channel belts in the depositional stretches of a river system.

Channel-belt formation – a single flood event



Indus River in 2010: heavy rainfall from day 208-210 (July 27th-30th)
Flood wave travels through the main channel in 10 days, then into the delta in 10 days. Flood wave travels through breach and low-lying floodplains in 42 days.

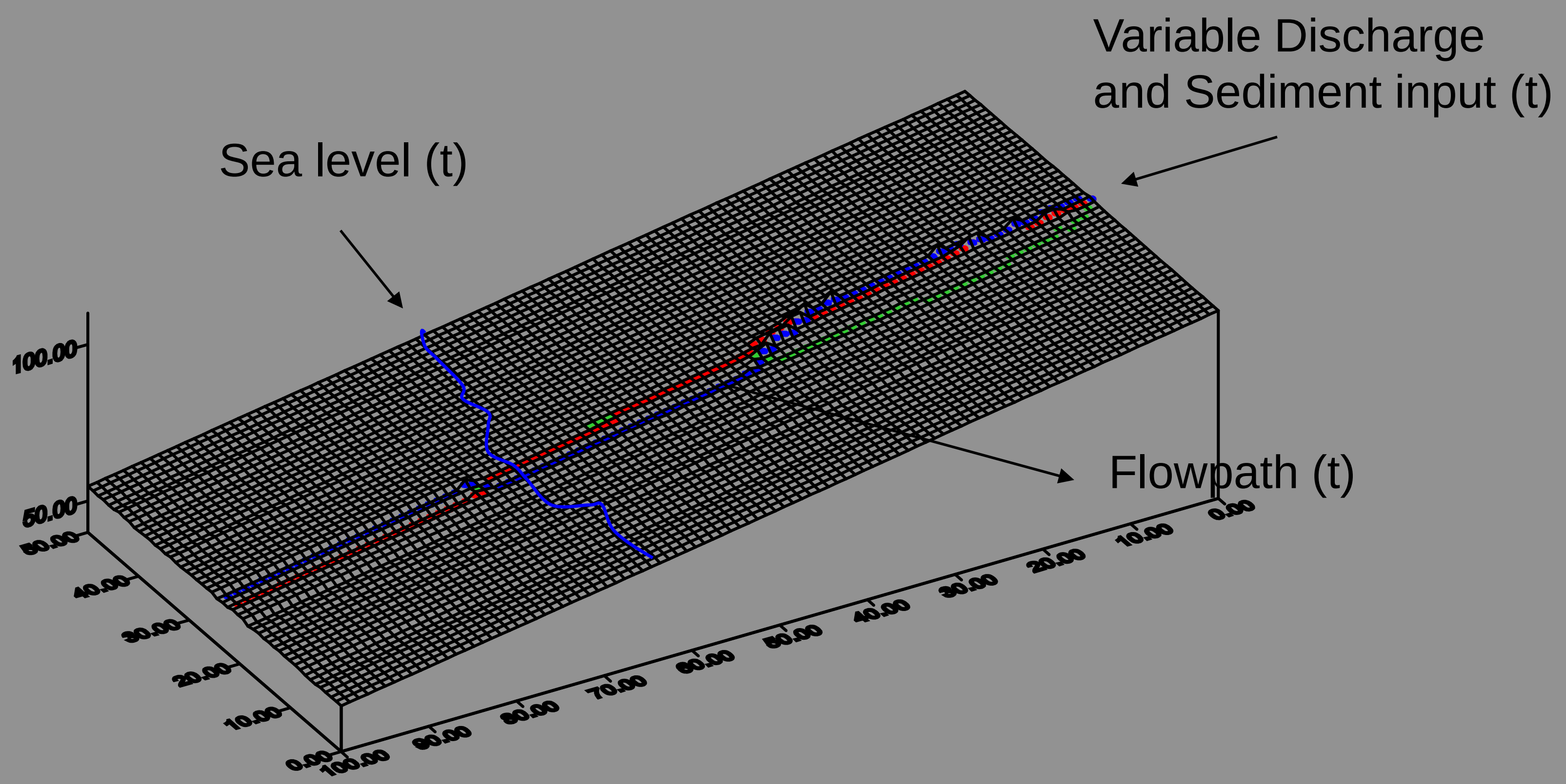


Lateral migration during the 2010 flood, was 339 m in just 52 days on average along 1000 km of its lowland river length.

Stratigraphic Research Questions

- What is the internal architecture of channel belts?
- How does stratigraphy vary downstream?
- How are channel belts impacted by different flooding regimes?
- Under what flooding conditions are deposits amalgamated?

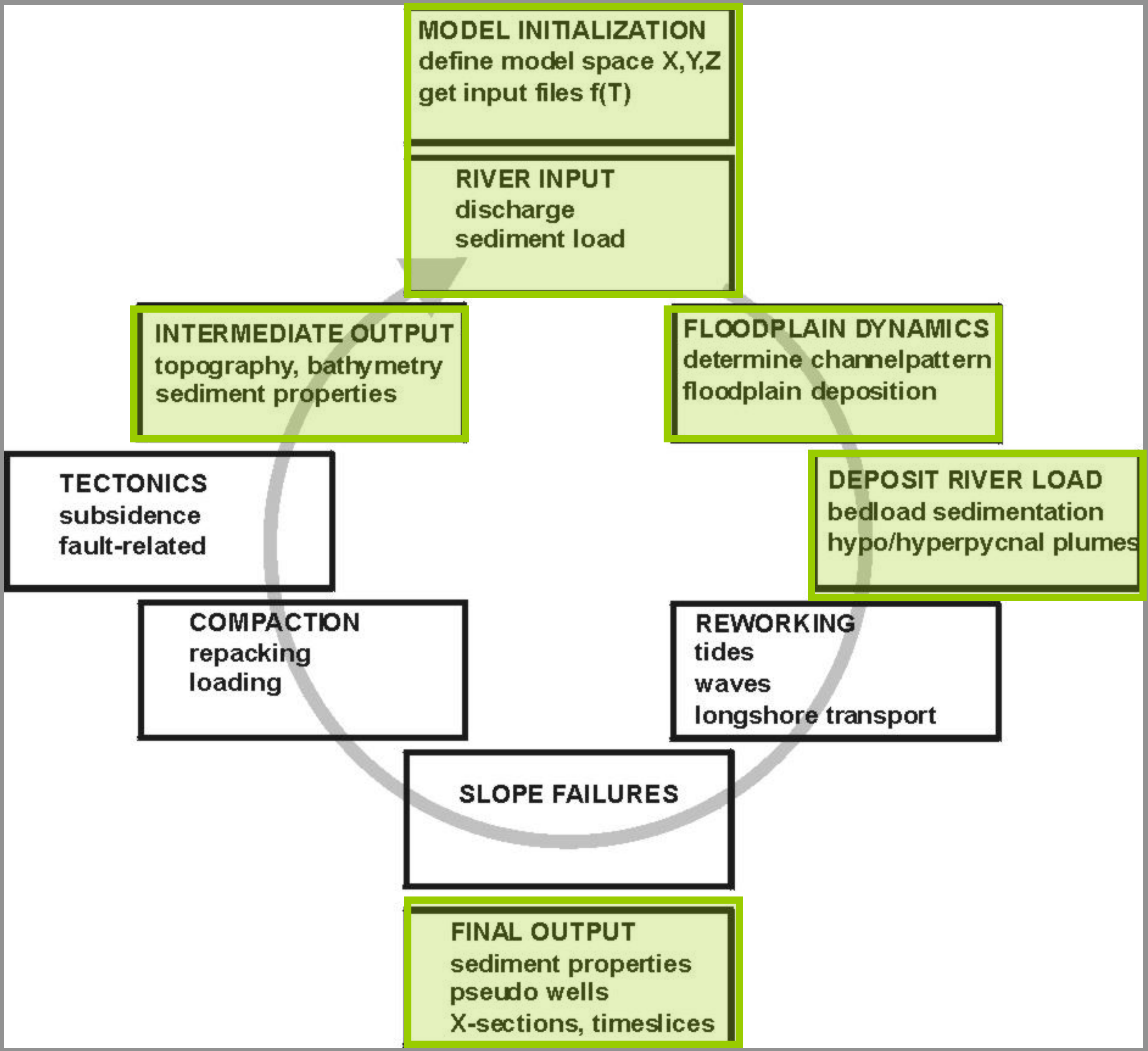
Methodology: Numerical Model AquaTellUs



AquaTellUs is designed for stratigraphic predictions

- Model runs for multiple grain sizes; bedload, 3-5 classes of suspended load.
- Model preserves layering in time, flow baffles are preserved
- Timescale of flood events, duration of 10^3 – 10^4 of years

Stand-Alone Model Architecture



Erosion/Sedimentation along Flowpath

$$\frac{\partial H_x}{\partial x} = \frac{\partial F}{\partial x} + T$$

Topography (H) depends on sediment flux (F) and tectonics (T)

erosion →

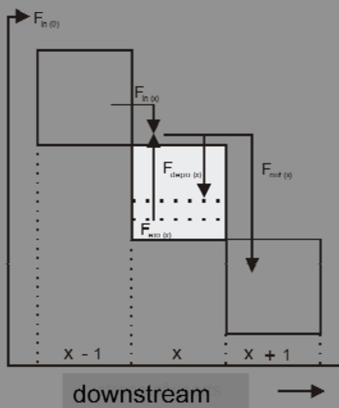
$$\frac{\partial \boldsymbol{F}_{er}}{\partial \boldsymbol{x}} = \boldsymbol{k}_{c(x,t)} \boldsymbol{S}_{(x,t)}{}^{m} \boldsymbol{Q}(\boldsymbol{x})_{(t)}$$

Erosion depends on slope (S) and discharge (Q) in fluvial domain, grain-size-independent

sedimentation

$$\frac{\partial F_{sed(x,t)}}{\partial x} = \frac{k_{sed}}{u_{(x,t)}} F_{(x,t)}$$

Sedimentation depends on sediment flux (F) and the streampower (u); k_{sed} is grain-size-dependent.



Presenter's notes: Exner Equation, first principles (Paola 1992).

Lateral Sediment Distribution

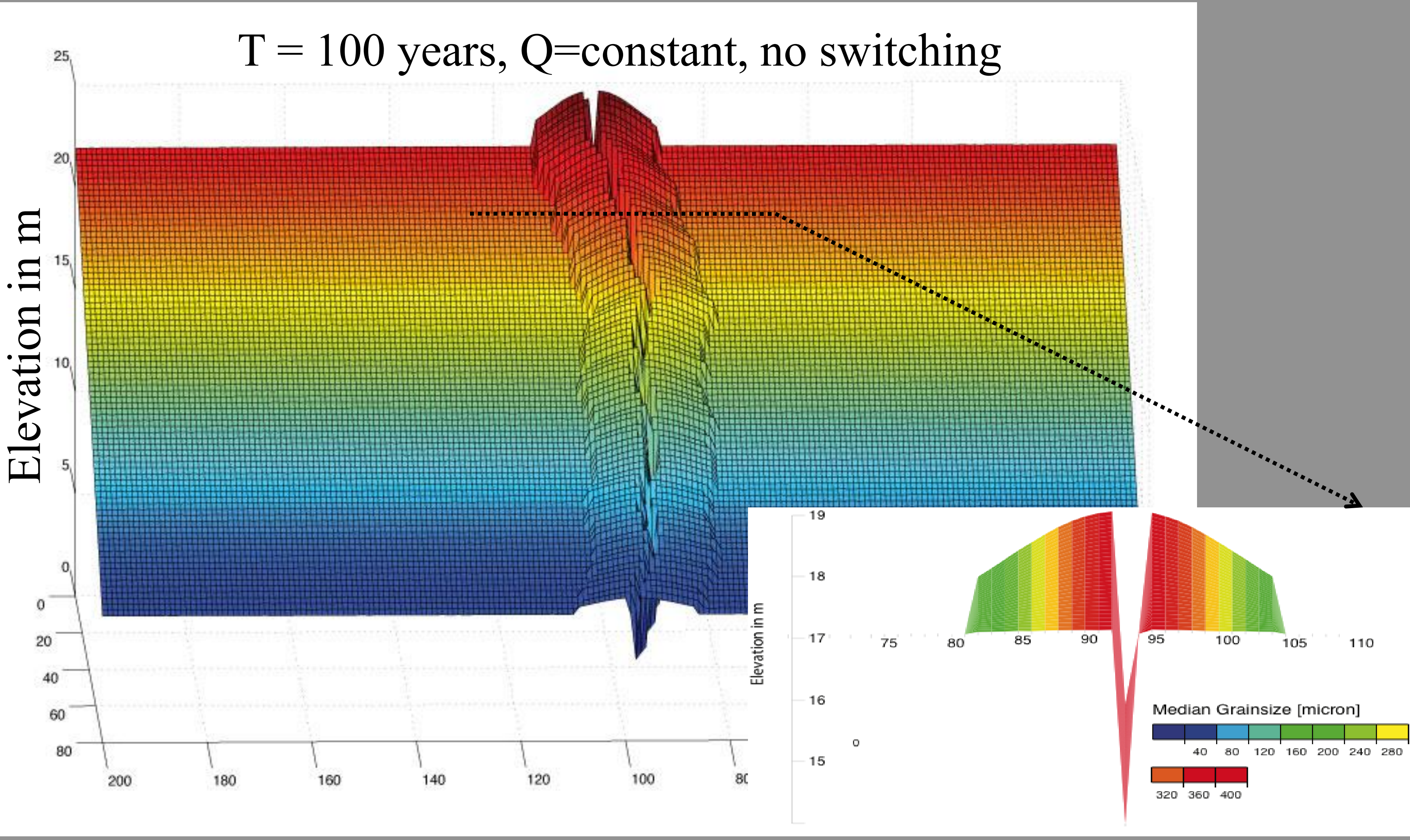
Basic principles of sedimentation across channel belt and floodplain:
• Exponential with distance from channel (Pizutto, 1987; Goodbred & Kuehl, 2000).

• Variability in floods creates Gaussian distribution; and error function solution (Paola, 2000; Overeem, 2005).

$$F(y) = \frac{1}{\sqrt{2\pi\sigma}} e^{\frac{-(y-\mu)^2}{2\sigma^2}} \longrightarrow erf(y) = \frac{2}{\sqrt{\pi}} \int e^{-t^2} dt$$

y = horizontal distance normal to flowpath
σ = standard deviation across sedimentation zone
μ = position of flowpath axis

Planview Simplest Channel Belt

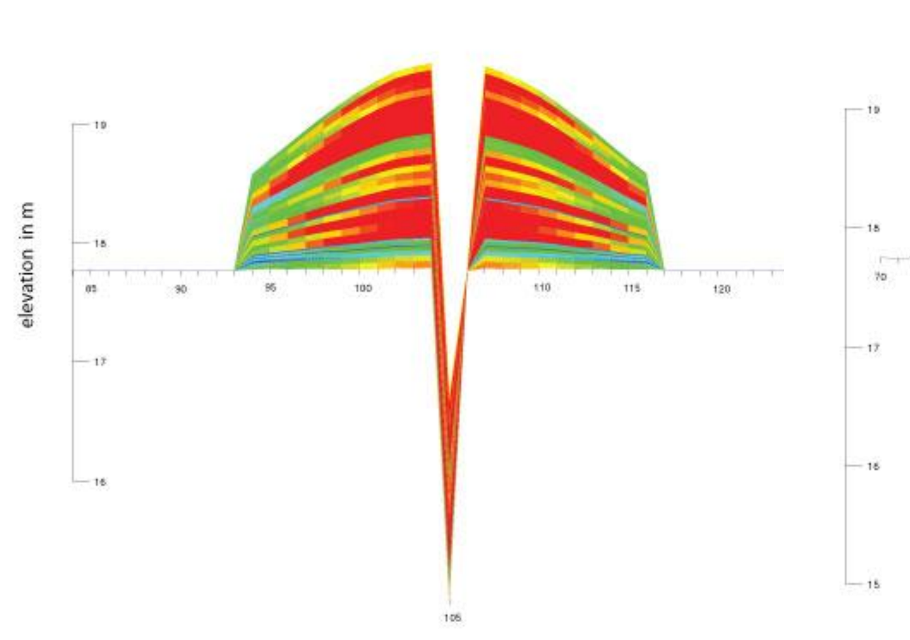


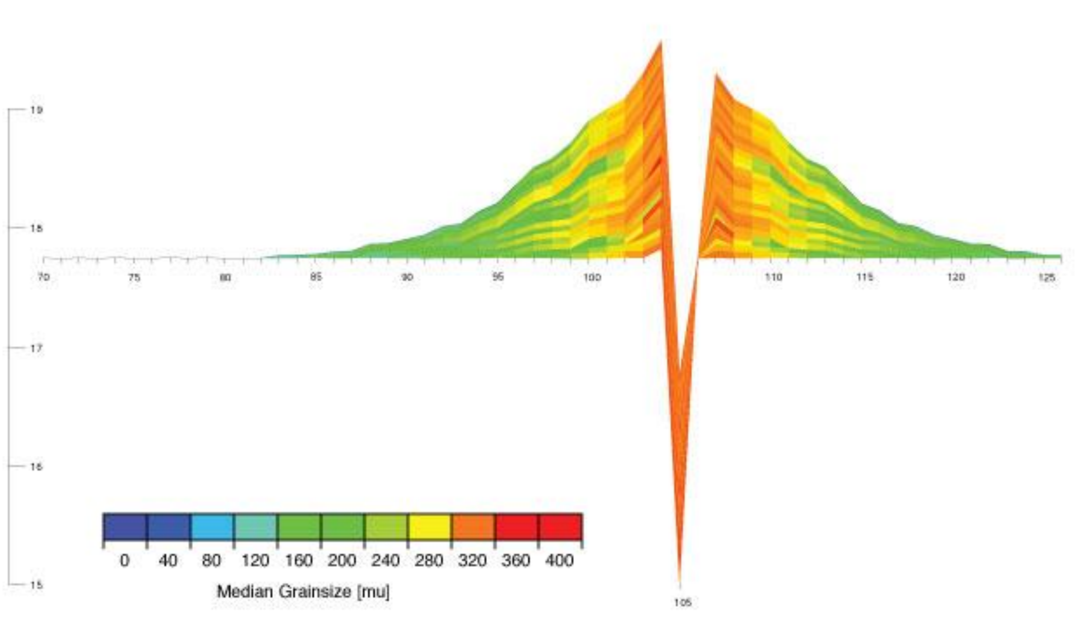
Distance in gridcells (1000m)

Depositional topography ~ discharge variability

Variable flood discharge,
constant flooding zone

Variable flood discharge,
dynamic flooding zone



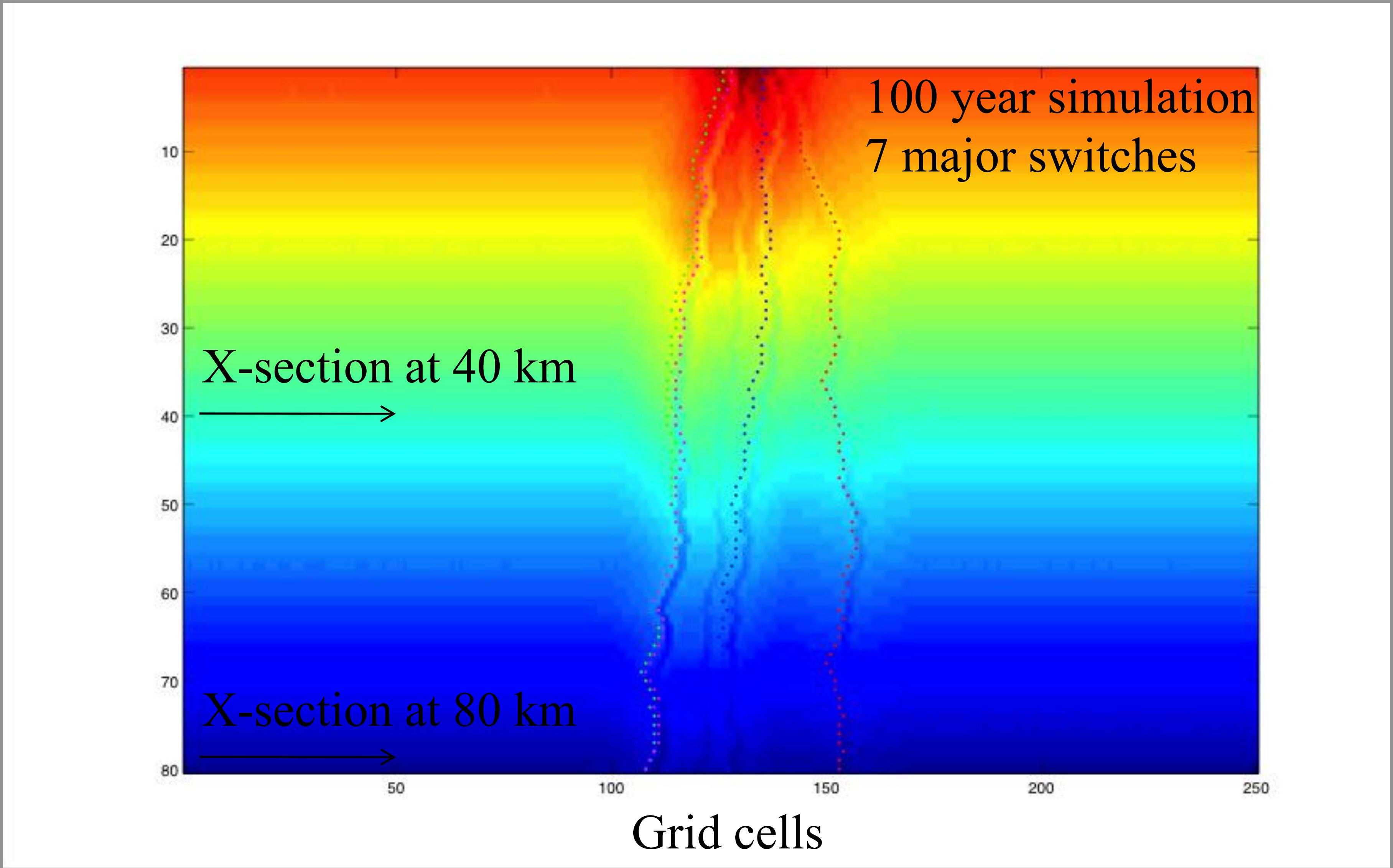


Paola (2000) theory
Error function as description
for Gaussian distribution

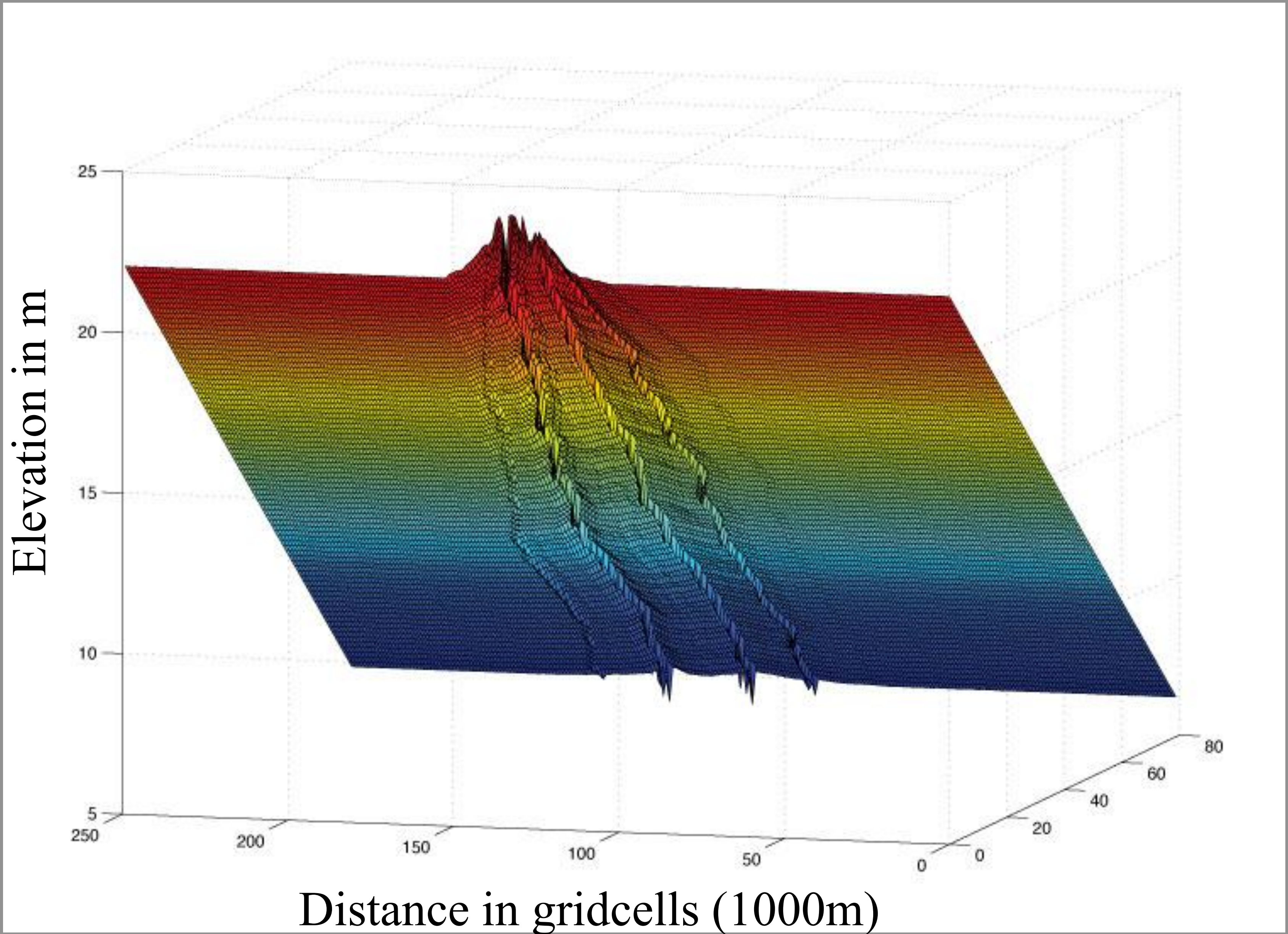
→

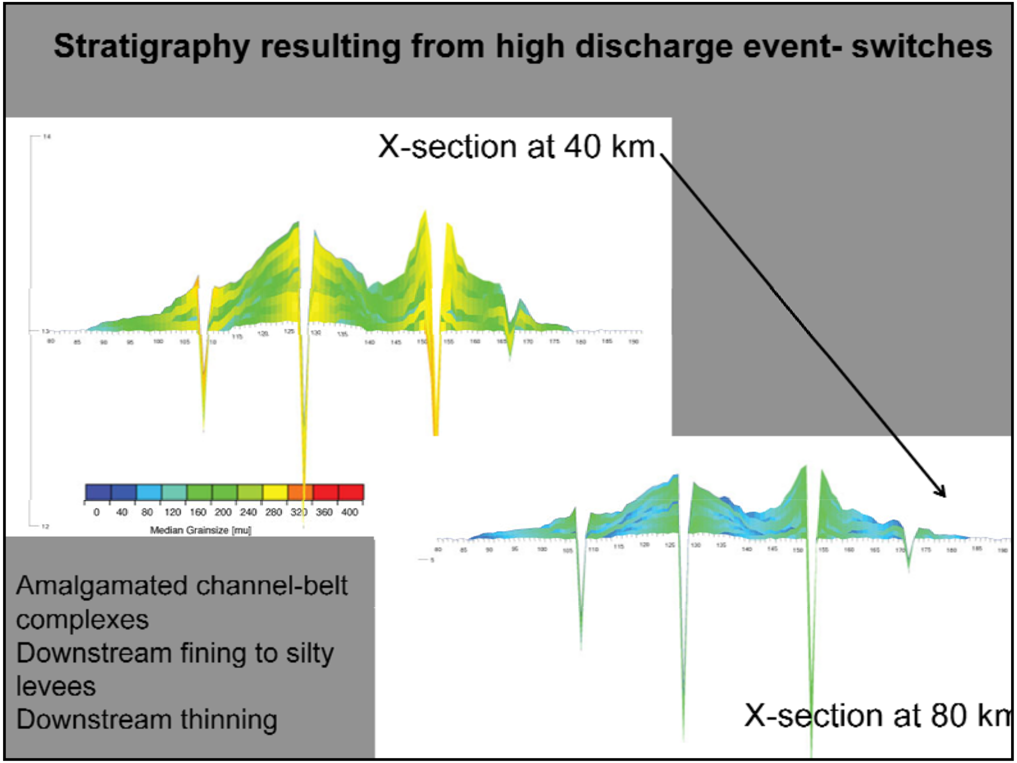
Error function with variability
better matches field observations:
e.g., Pizutto, Goodbred, Middelkoop,
Asselman and earlier example

Switch threshold ~ Discharge variability



Planview Multiple Channel Belts



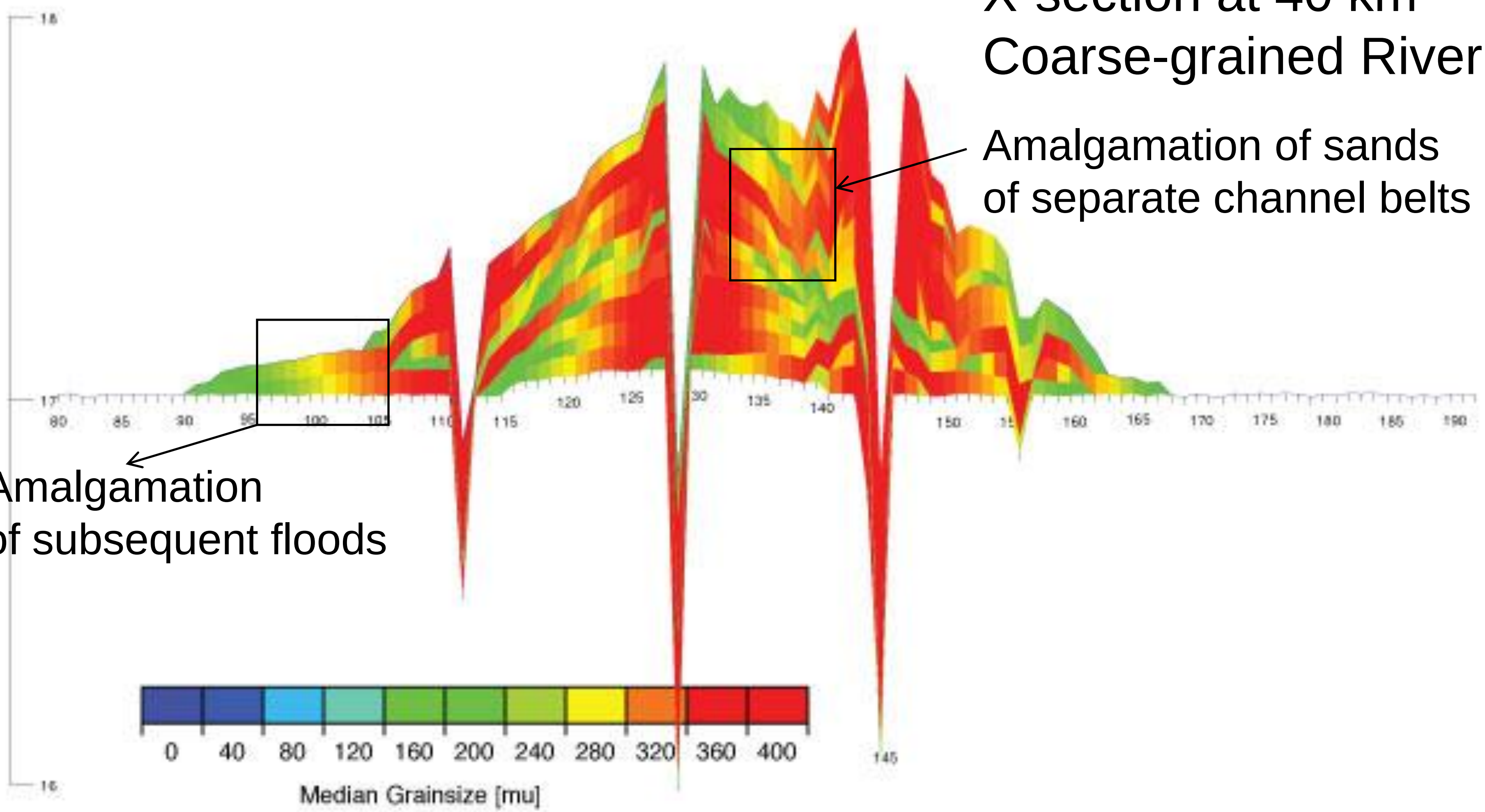


Presenter's notes: Downstream fining to silty levees in fluvio-deltaic floodplain; Downstream thinning.

Interconnectivity of Channel belts?

X-section at 40 km
Coarse-grained River

Amalgamation of sands
of separate channel belts



Amalgamation
of subsequent floods

Summary

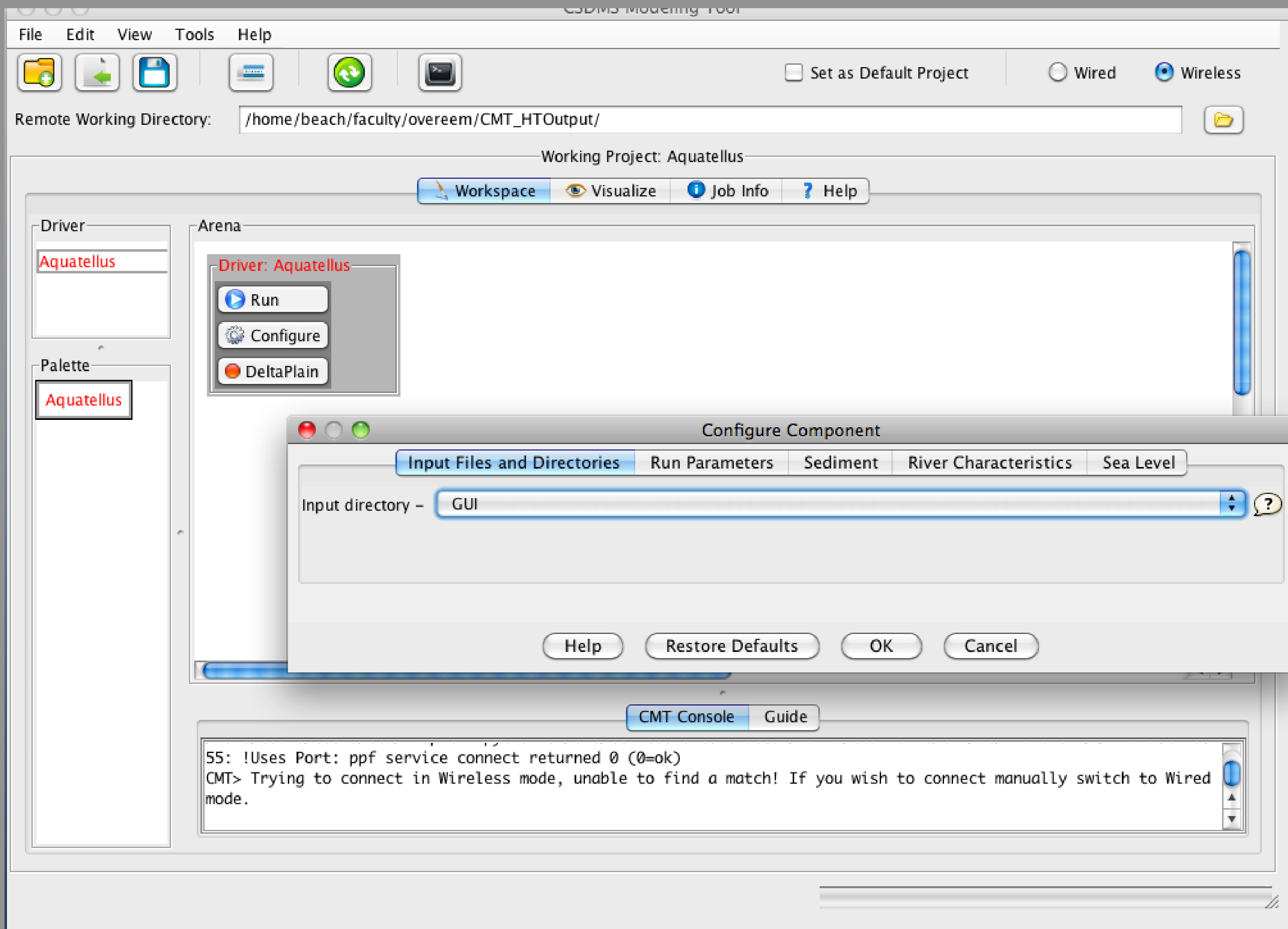
- AquaTellUs models stratigraphic architecture of ‘recent’ channel belts and at first inspection matches field observations

- Channel-belt topography is affected by discharge variability; it self-organizes to an exponential shape with larger variability.

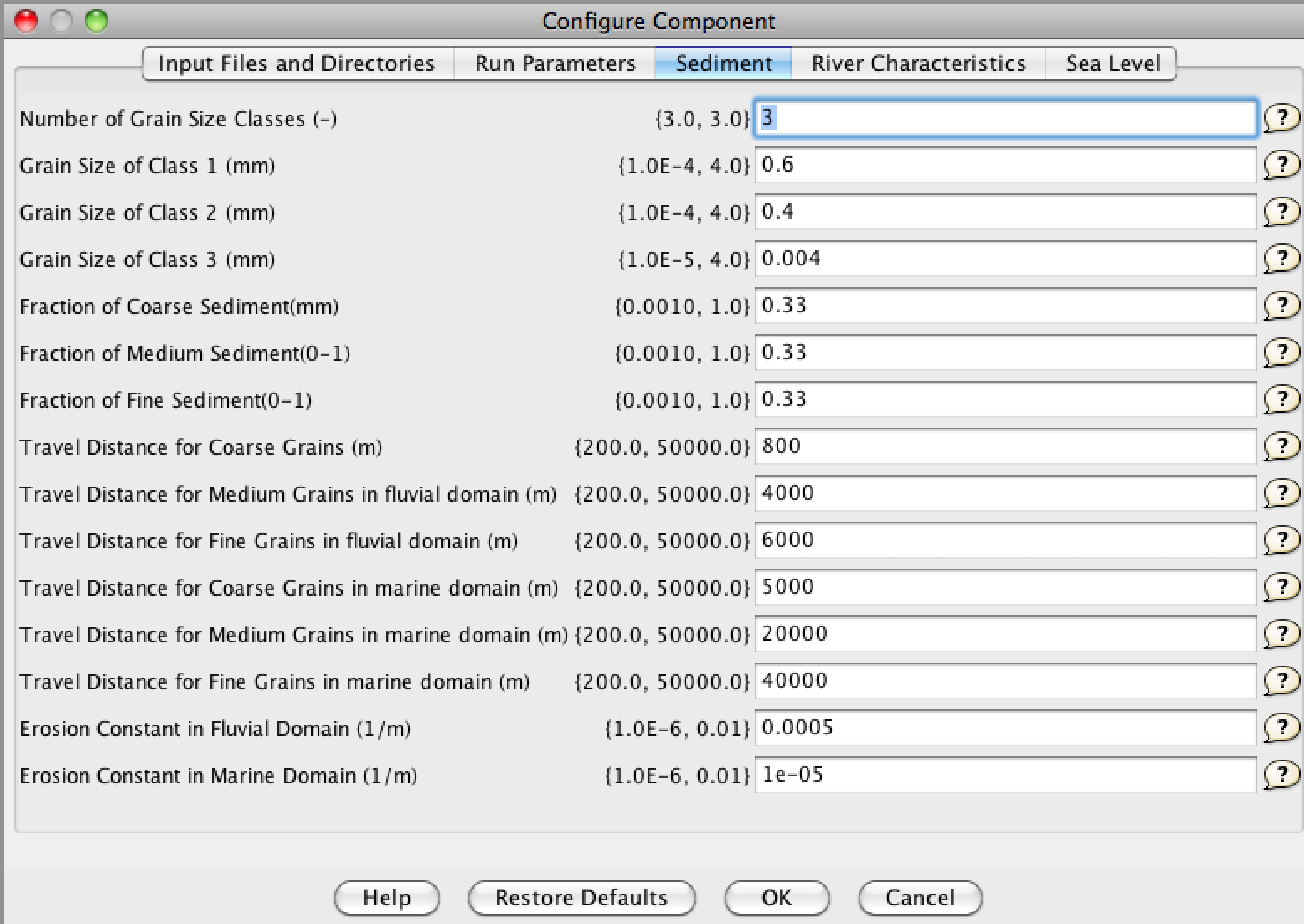
- Model predicts strong downstream fining, predominantly a consequence of sediment availability. Siltier, lower channel belts occur towards the coastal floodplain

- Model predicts significant interconnectivity in coarse-grained river simulations, both between events and between channel belts.

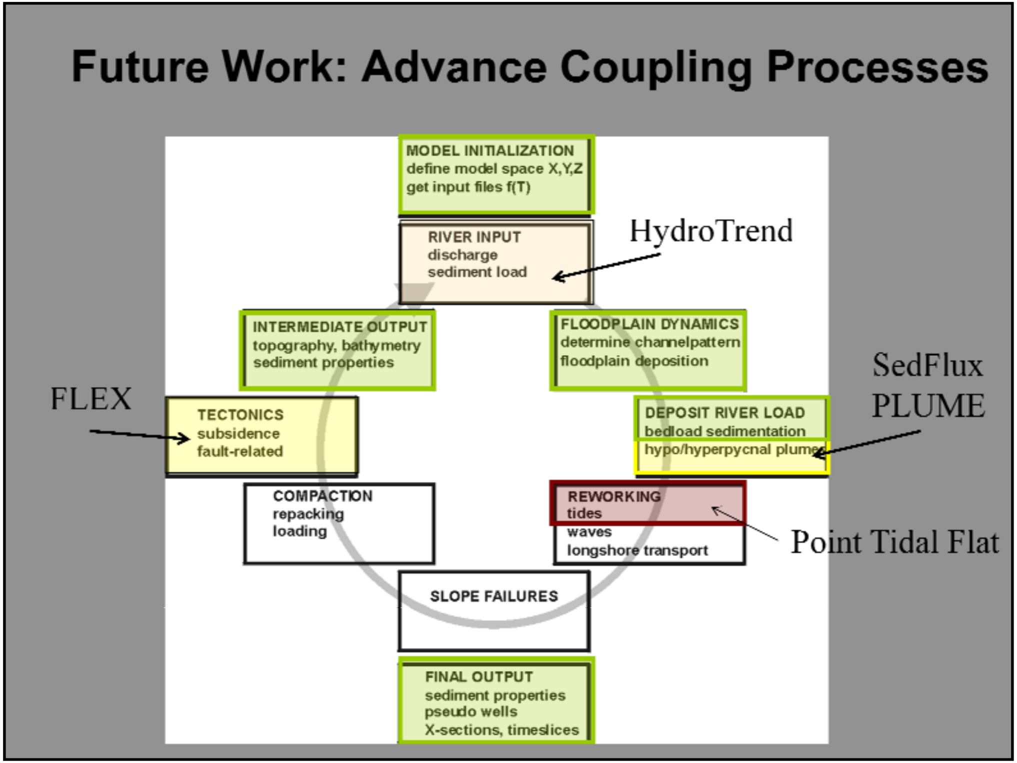
Near Future: AquaTellUs is CSDMS component



AquaTellUs Example Input for Sediment



Most parameters are now in control of users, not all yet, work in progress



Presenter's notes: This requires more work on basic code and BMI; make as many parameters as possible passable. Model will benefit and become more robust.

References

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