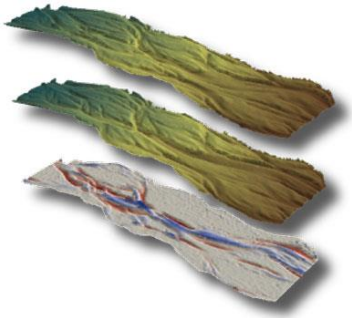
GEOMORPHIC CHANGE DETECTION

U. SPATIAL COHERENCE & PROBABILISTIC BAYESIAN UPDATING

Stream Restoration Courses



April 30th to May 1st , 2014

Sponsored by:

Utah State University
DEPARTMENT OF WATERSHED SCIENCES

ICRRR
Intermountain Center for River Rehabilitation and Restoration

NORTH ARROW RESEARCH

WORKSHOP PLAN – DAY 2… (AFTERNOON)

Q. Building your own FIS Error Models — 1:30 – 2:30

R. Self Paced - Inputs — 2:30 -3:00

S. Self Paced – Change Detection — 3:00 – 3:30

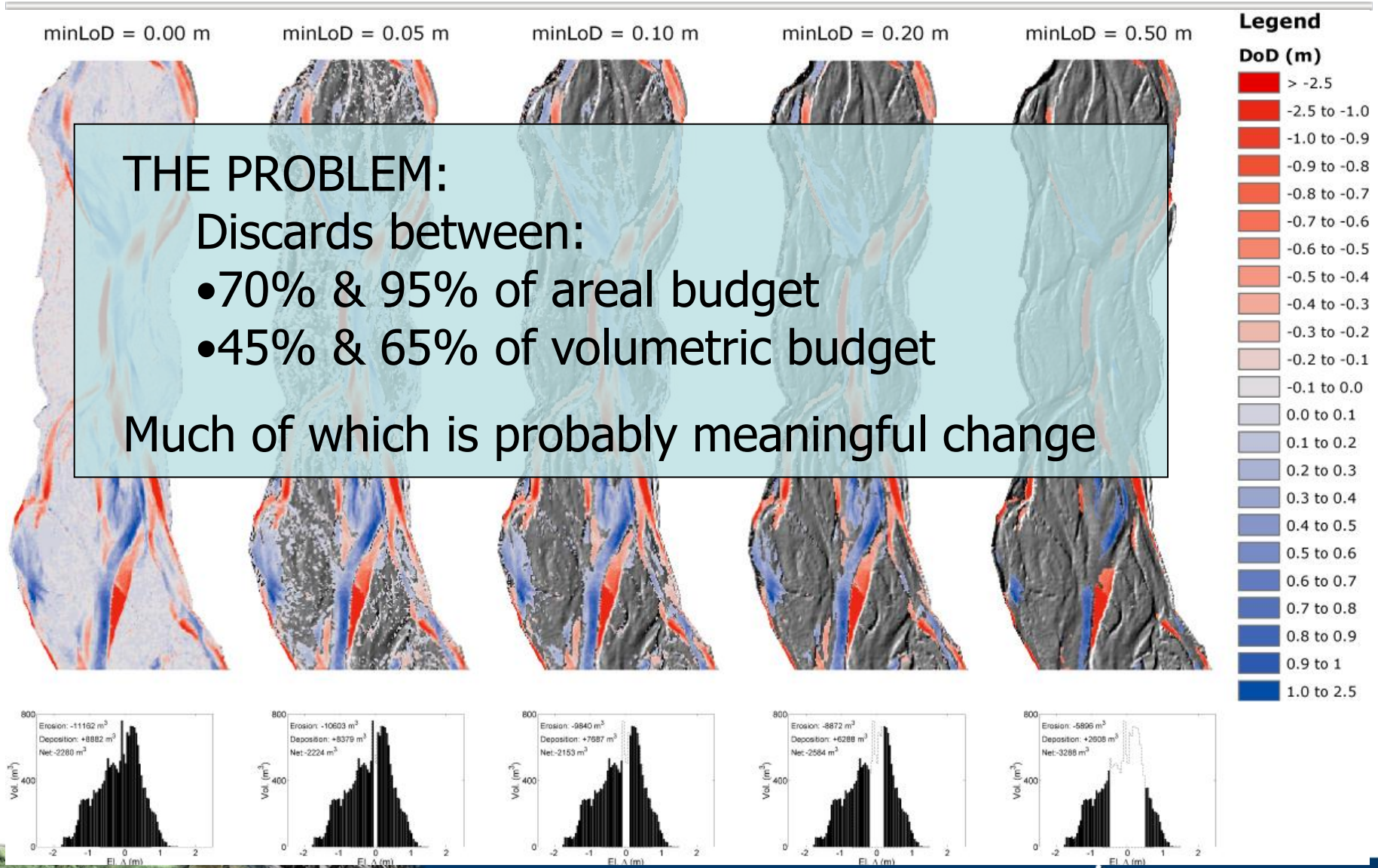
3:30 to 3:45 BREAK

T. Interpreting Outputs — 3:45 to 4:15

U. Spatial Coherence & Bayesian — 4:15 to 4:45

V. Recap / SLOP — 4:45 to 6:00

PROBLEM WITH THRESHOLDING… THE SMALL STUFF



THE PROBLEM:

Discards between:

- 70% & 95% of areal budget
- 45% & 65% of volumetric budget

Much of which is probably meaningful change

THIS IS FROM THE BACKGROUND READING

- Two methodological advances
  1. Fuzzy Inference Systems
  2. **Spatial Coherence Filter & Bayesian Updating**

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Accounting for uncertainty in DEMs from repeat topographic surveys: improved sediment budgets

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ESPL
Earth Surface Processes and Landforms

ABSTRACT: Repeat topographic surveys are increasingly becoming more affordable, and possible at higher spatial resolutions and over greater spatial extents. Digital elevation models (DEMs) built from such surveys can be used to produce DEM of Difference (DoD) maps and estimate the net change in storage terms for morphological sediment budgets. While these products are extremely useful for monitoring and geomorphic interpretation, data and model uncertainties render them prone to misinterpretation. Two new methods are presented, which allow for more robust and spatially variable estimation of DEM uncertainties and propagate these forward to evaluate the consequences for estimates of geomorphic change. The first relies on a fuzzy inference system to estimate the spatial variability of elevation uncertainty in individual DEMs while the second approach modifies this estimate on the basis of the spatial coherence of erosion and deposition units. Both techniques allow for probabilistic representation of uncertainty on a cell-by-cell basis and thresholding of the sediment budget at a user-specified confidence interval. The application of these new techniques is illustrated with 5 years of high resolution survey data from a 1 km long braided reach of the River Feshie in the Highlands of Scotland. The reach was found to be consistently degradational, with between 570 and 1970 m^3 of net erosion per annum, despite the fact that spatially, deposition covered more surface area than erosion. In the two wetter periods with extensive braid-plain inundation, the uncertainty analysis thresholded at a 95% confidence interval resulted in a larger percentage (57% for 2004–2005 and 59% for 2006–2007) of volumetric change being excluded from the budget than the drier years (24% for 2003–2004 and 31% for 2005–2006). For these data, the new uncertainty analysis is generally more conservative volumetrically than a standard spatially-uniform minimum level of detection analysis, but also produces more plausible and physically meaningful results. The tools are packaged in a wizard-driven Matlab software application available for download with this paper, and can be calibrated and extended for application to any topographic point cloud (x,y,z). Copyright © 2009 John Wiley & Sons, Ltd.

KEYWORDS: DEM of Difference (DoD); fluvial geomorphology; morphological method; morphological sediment budgeting; River Feshie; fuzzy inference system

Introduction

With recent advances in ground-based, boat-based and remotely-sensed surveying technologies, the rapid acquisition of topographic data is now possible at spatial resolutions and extents previously unimaginable (Lane and Chandler, 2003; Heritage and Hetherington, 2007; Milan *et al.*, 2007; Marcus and Fonstad, 2008; Notebaert *et al.*, 2008). These advances make monitoring geomorphic changes and estimating sediment budgets through repeat topographic surveys and the application of the morphological method (Church and Ashmore, 1998) a tractable, affordable approach for monitoring applications in both research and practice. In fluvial geomorphology, the morphological approach has been used as an alternative to measuring sediment transport directly and has historically been applied primarily to repeat surveys of river plan form, cross-sections and/or longitudinal profiles (Brewer and Passmore, 2002; Lane, 1998). However, from the early 1990s (Lane *et al.*, 1994), the morphological method has been expanded to include the use of repeat topographic surveys from which digital elevation models (DEMs) could be constructed and differenced to produce DEMs of Difference (DoDs). This paper focuses exclusively on the 2D application of the morphological method using DoDs.

Uncertainty in DoD application of the morphological method has already received considerable attention (Lane *et al.*, 1994; Milne and Sear, 1997; Brasington *et al.*, 2000; Lane, 1998; Lane *et al.*, 2003). Driving this interest has been the basic question that, given the uncertainty inherent in individual DEMs, is it possible to distinguish real geomorphic changes from noise? Repeat surveys using rtkGPS (Brasington *et al.*, 2000), total stations (Milne and Sear, 1997), aerial photogrammetry (Winterbottom and Gilvear, 1997; Westaway *et al.*, 2001), multi-beam echo-sounding (Calder and Mayer,

DETAIL PLAN – I.

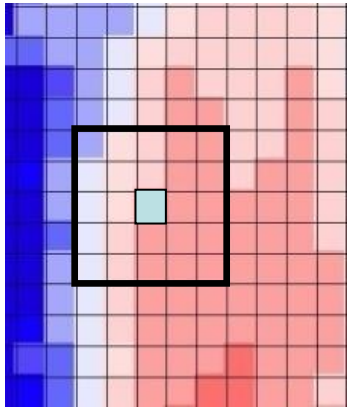
I. Alternative Approaches to Geomorphic Change Detection

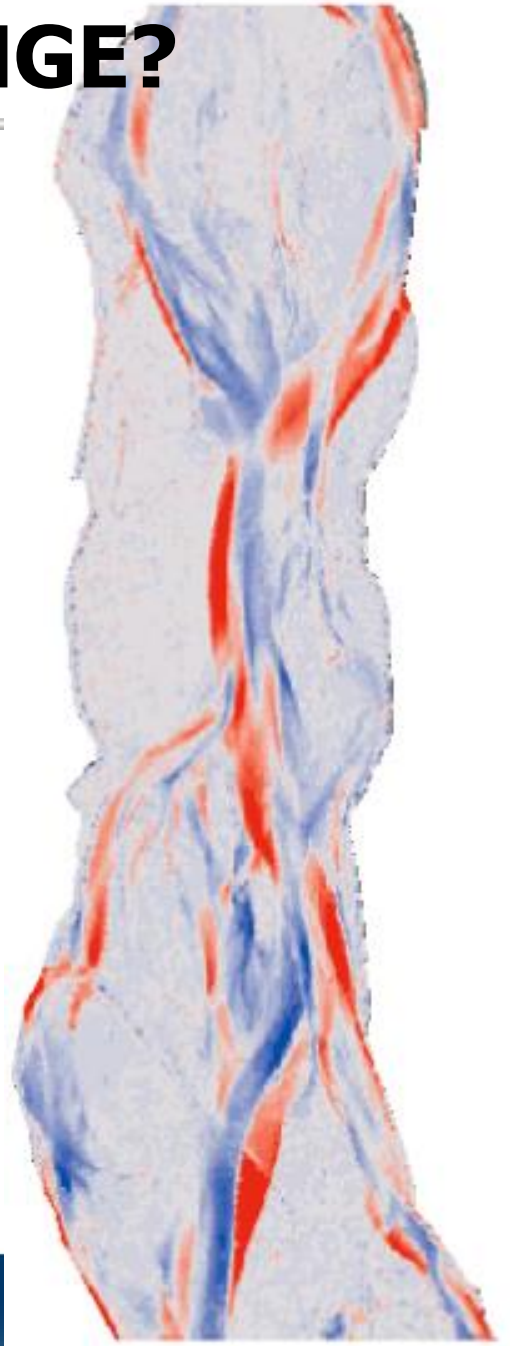
A. Coherence Filter & Bayes Theorem

B. Run Spatial Coherence Filter & Do Bayesian Updating

SPATIAL COHERENCE OF CHANGE?

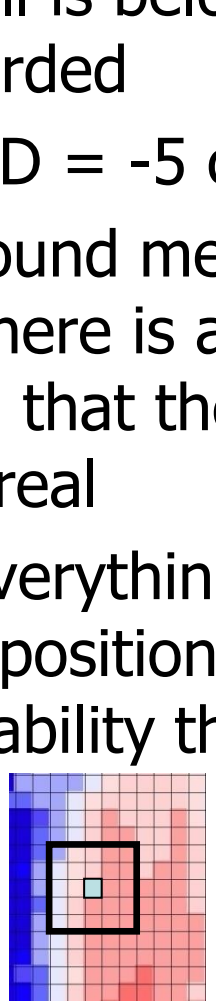
- Is change map a checkerboard of blue and red or do changes exhibit coherent spatial patterns?
- PREMISE:
  - Change is more believable if it is spatially consistent with its neighbors

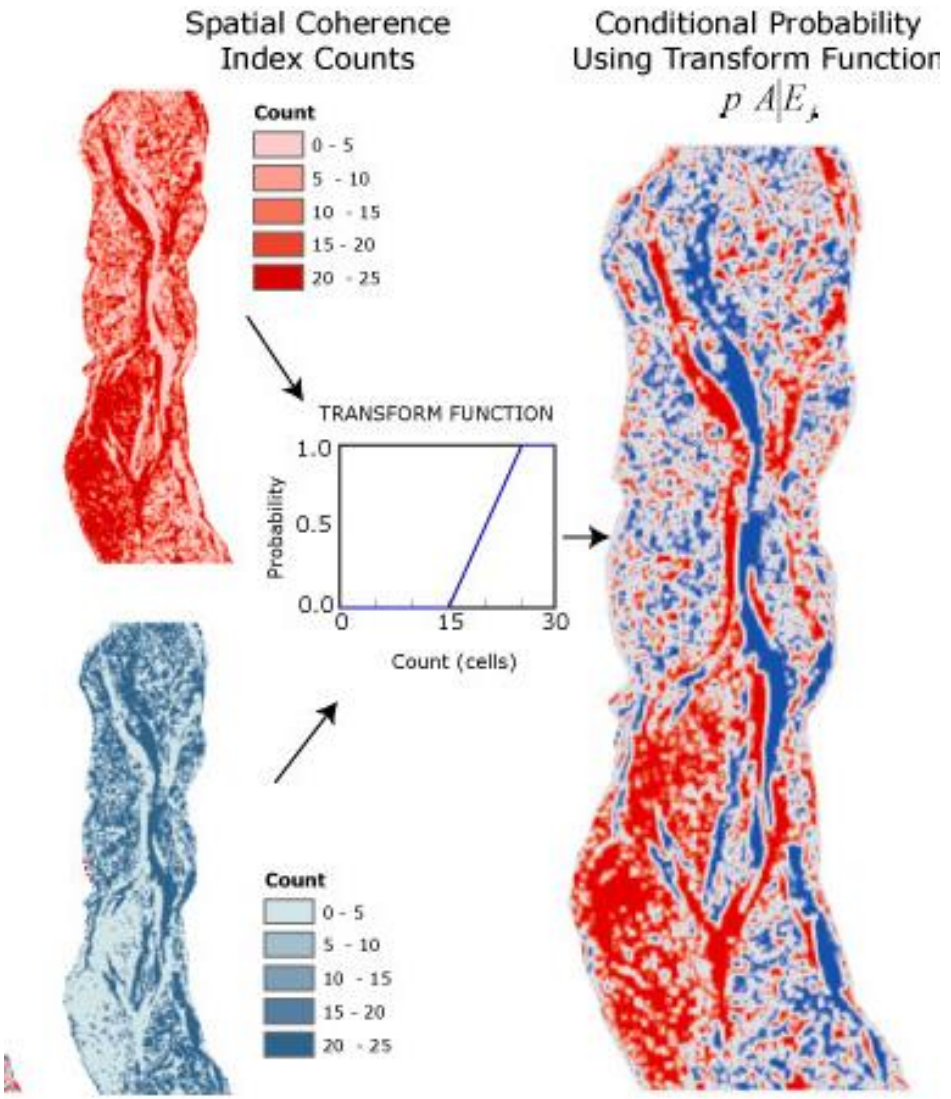




SPATIAL COHERENCE FILTER

- Normally, if a cell is below $_{min}$LoD it is discarded
- Let normal $_{min}$LoD = -5 cm
- If everything around me is also erosional, there is a higher likelihood that the small change is real
- By contrast, if everything around me is depositional, then lower probability that change is real

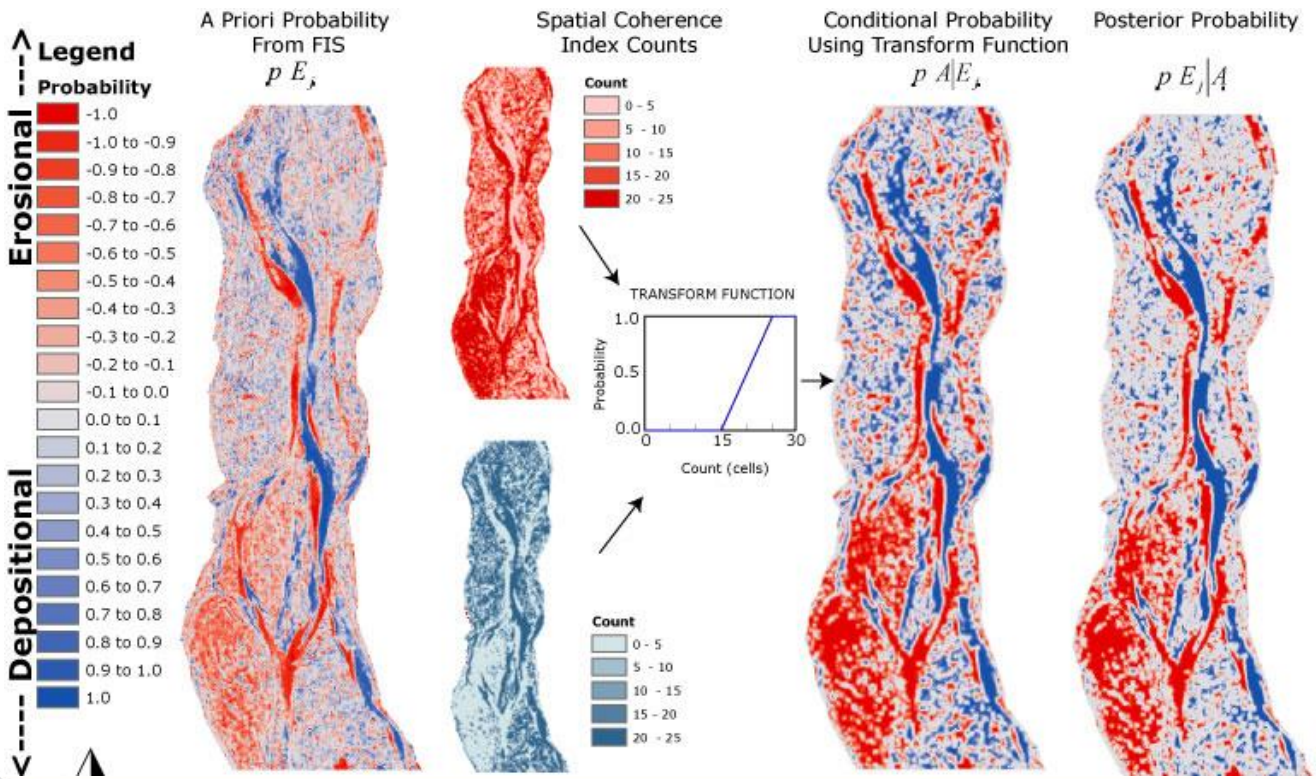




UPDATE USING BAYES THEOREM

$$p(E_j|A) = \frac{p(A|E_J) \cdot p(E_j)}{p(A|E_J) \cdot p(E_j) + p(A|E_i) \cdot p(E_i)}$$

- $P(E_j|A)$ is updated (posterior probability)
- $P(E_j)$ is initial probability (a priori probability)
- $P(A|E_j)$ is conditional probability using spatial coherence filter (new information)
- Subscript *i* denotes inverse probability



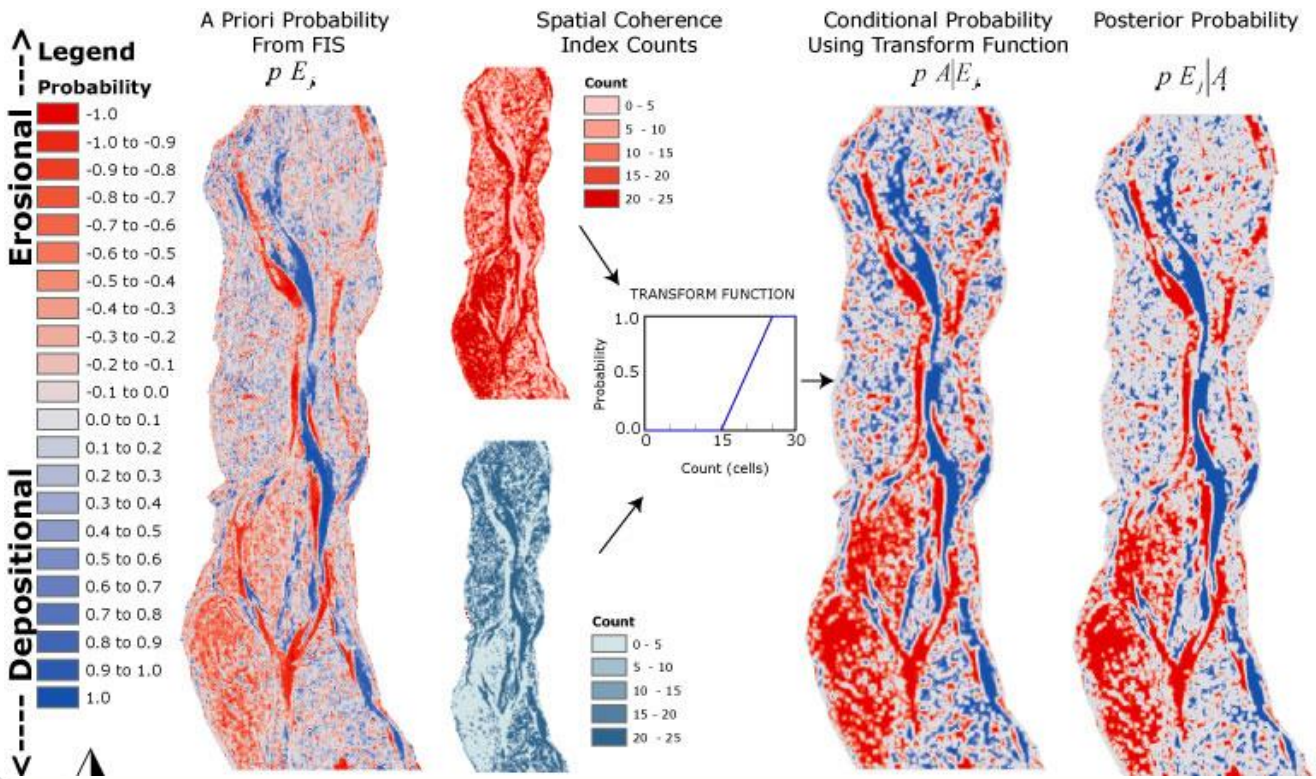
EXAMPLE: WHAT IS $P(E_j|A)$?

$$p(E_j|A) = \frac{p(A|E_J) \cdot p(E_j)}{p(A|E_J) \cdot p(E_j) + p(A|E_i) \cdot p(E_i)}$$

$$p(E_j|A) = \frac{0.85 \bullet 0.68}{(0.85 \bullet 0.68) + (0.15 \bullet 0.32)} = 0.92$$

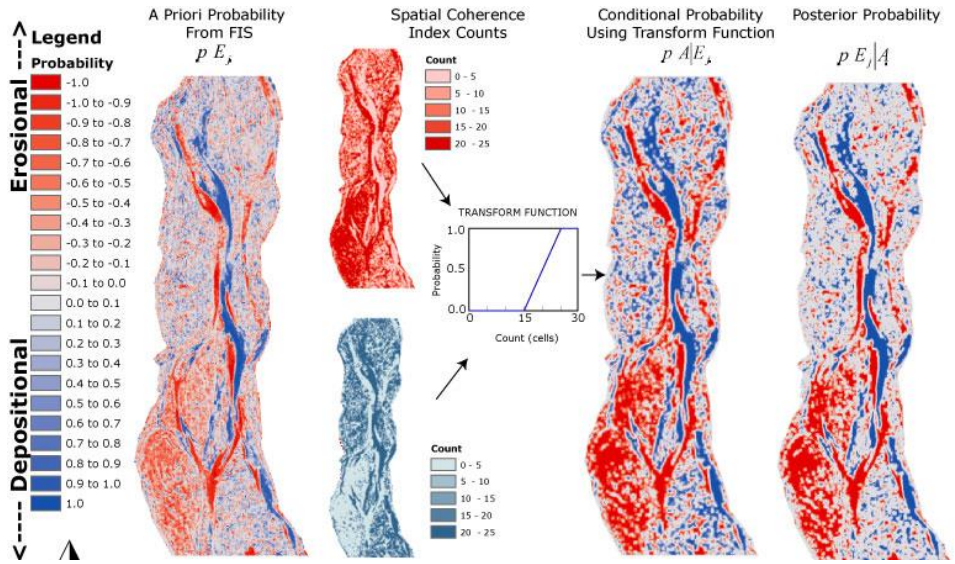
LET:

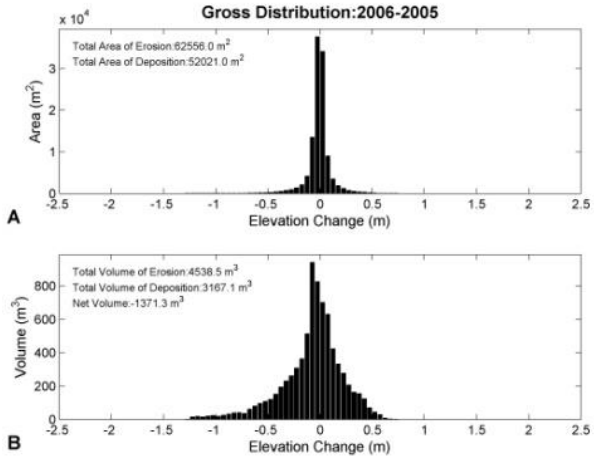
- $P(E_j) = 0.68$
- $P(A|E_j) = 0.85$
- In other words, additional information from spatial coherence index increased probability that change is real….

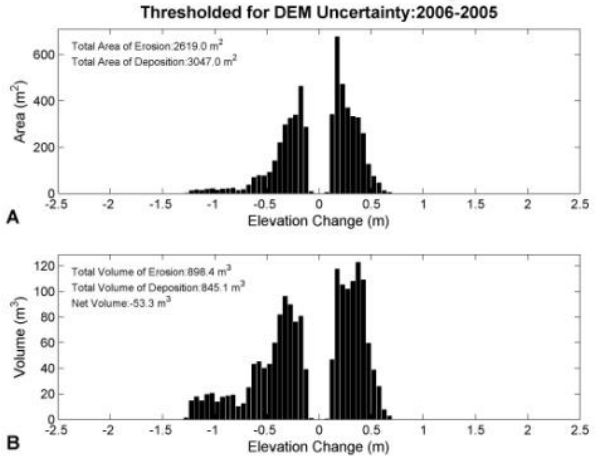


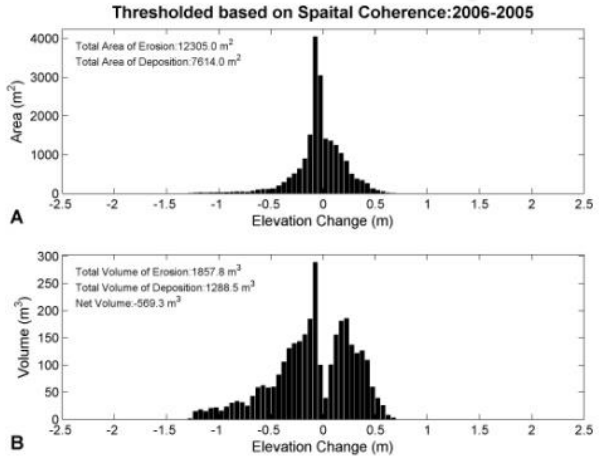
INFLUENCE OF SPATIAL COHERENCE FILTER

- Effectively a better spatial discriminator
- For ECD, recovers some low magnitude changes





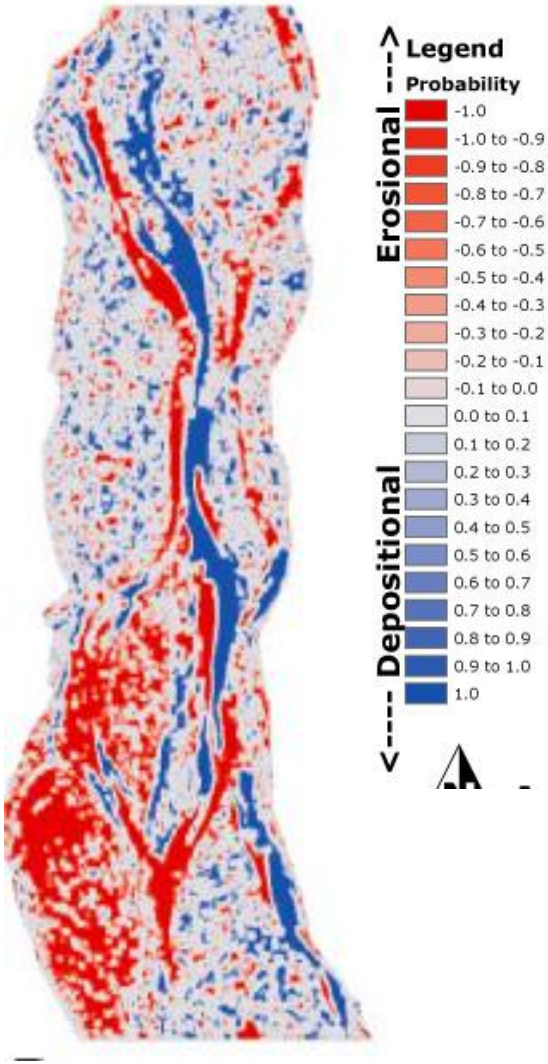




USEFULL BUT… BE CAREFUL

- We get an updated map of probability that change is real

- Be careful with systematic errors…
- Could be used with other conditional probabilities…



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RUNNING BAYESIAN UPDATING IN GCD

- Use Bayesian Updating