# Response to reviewer 1

We would like to thank the reviewer 1 for his meaningful comments that will significantly help us to improve the quality of the paper. We first reply the reviewer's general comments integrated in bold italic along the text. Then, we added a step by step response to the specific comments that were integrated in the pdf by the reviewer in a separate document. All substantial modifications that were included in the revisited version of the manuscript are written in blue.

1. General comments

This is an original and innovative paper; to my knowledge it is the first manuscript submitted to a peer-reviewed journal that describes the use of a network representation of sediment cascades derived from a geomorphological map, and its analysis using tools of graph theory. Such analysis has been suggested in the literature, and there are very few studies along these lines that have been presented at scientific meetings. The authors make use of a didactic example for the computation of graph theoretic centrality and accessibility measures, and develop a connectivity index that is based on the two measures. The approach is then applied to a case study of sediment cascades in a catchment in the French Alps. The topic is highly interesting for the scientific community investigating sediment budgets, cascades and connectivity. However, I have several comments and concerns that should be addressed before the manuscript can be recommended for publication.

My major concerns are (1) The structure of the paper. It does not follow the 'normal' scheme; therefore, the introductory/review part and the development part plus the case study need to be better separated in my opinion. Graph theory, a central topic of this paper, is introduced in the state-of-the art section, together with the Borselli-Cavalli index in 2.1, and then more specifically with respect to undirected graphs in 2.2. Chapter 3 is termed "methods to assess structural connectivity" (Borselli's IC is one, right?), followed by specific analyses related to directed graphs in 3.1 and 3.2 before you propose your own index in 3.3.

My suggestion would be to cut down on the review part and to write a more specific introduction to graph theoretical methods related to connectivity, both in the undirected and directed case. In my opinion, the analysis of potential flows goes beyond structural connectivity, and recent modelling studies using graphs as the 'spatial backbone' to model sediment fluxes through a catchment should be addressed, c.f. Rafael's comments. Generally, the graph theoretic measures such as centrality, accessibility etc. should be accompanied by references. The Borselli or Cavalli index could be described in the introduction to section 2, and with less detail unless more references to this index is made in the remaining text, for example by highlighting similarities and differences, or by discussing amendments to the proposed graph-theoretic index along the lines of parameters contained in the Borselli-Cavalli index. The main section could then be devoted to the development of 'your' index (and should be termed accordingly).

***We agree with this comment and we recognize that the initial structure of the paper may have been confusing for the reader.***

***The balance between section 2, 3 and 4 was reconsidered. The section 2 "state of the art" is now splitted in 2 sub-sections: 2.1. "Assessment of structural sediment connectivity" were we introduce the Borselli-Cavalli indices and 2.2. "Graph theory applications to structural connectivity" that concerns both undirected and directed applications of graph theory. The section 3 "Methodology: the IC index" is specifically devoted our IC index and its major components: 3.1 potential flow and 3.2. Accessibility. Then the IC index in 3.3 and finally the sub-section 3.4 that presents the method***

***used for the spatial segmentation of the geomorphological map. The section 3 is now only methodological, so that the reference to both virtual sediment cascade and the Alpine case study were moved to the results section. Additionally, a new figure (now fig. 1) was added to summarize and to be more explicit on the combination of indices that lead to ours: the IC.***

(2) A poor linkage between the text, tables 1-3 and figures 1+2; this is evident in the flow index (Fig. 1C, Tab. 2) not being mentioned in the text, and in an error in Fig 1B (see specific comments).

***The references to tables and figures in the concerned section have been improved. The error you noticed in the figure (thank you!) has been corrected accordingly.***

(3) The didactic example does not account for divergent flow; transferred to the real case study, I think it is doubtful whether a landscape element in the order of 100 m (the discretisation applied to the geomorphological map) can always be linked exclusively to one single downslope neighbour, thus producing a network that is entirely convergent. Consider, for example, a talus cone whose one half is connected to the channel network through undercutting, and the other is buffered through a fluvial terrace. Then there would have to be two linkages from the cone, one to the fluvial system and one 'dead end' on the terrace; a single linkage would suggest in your model that all the material is transferred to the fluvial system. This issue needs to be discussed, if not accounted for at least in the didactic example. In case you choose to stick to the network representation with exclusively convergent pathways, this assumption needs to be stated and discussed.

***In a classical procedure of "flow analysis" in graph theory (Gleyze, 2008), fluxes can be either divergent or convergent. Here, we used a complex-reduced simulation to exhibit the role of the confluences within the network and fluxes are only convergent in our case study. Please refer to section 3.1 (page 7); you will find a more detailed description and justification of this choice.***

(4) Finally, there are several English language issues that I feel need to be corrected because they obscure the points being made.

***All specific comments on English language and spelling errors you mentioned in the attached pdf have been addressed. Additionally, the paper has been proofread by a professional English editing service.***

## 2. Specific comments

The step by step reply to the specific comments can be found in the following pdf file. Additionally, we join the list of the reviewer's comments numbered in the original pdf to help linking comments and replies with the original document.

## Summary of the comments on: esurf-2016-55-RCl-supplement-l.pdf

The reviewer's comments are listed page by page and numbered, based on the first manuscript (please see the attached document). Our responses are written in bold following each comment.

# Page: 1

Auteur: reviewer Subject: Notiz Date: 06/12/2016 10:05:29

this is a bit cryptic, especially "filiations"; please stick to the terminology accepted systems- and connectivity-related literature

**This was corrected accordingly: Filiations has been replaced by "links" – It was a mistranslation from French**

# Page 2

Number: 1 Author: reviewer Subject: Durchstreichen Date : 06/12/2016 10:03:31

**This was corrected accordingly**

Number: 2 Author: reviewer Subject: Eingefügter Text Date : 06/12/2016 10:04:02

A

**This was corrected accordingly**

Number: 3 Author: reviewer Subject: HervorhebenDate : 06/12/2016 10:08:23

Measurements don't lead to processes !

Suggestion: ...how erosion and sediment transfer on a small spatial scale interact to form broad-scale geomorphic patterns and processes.

**This was corrected accordingly**

Number: 4 Author: reviewer Subject: HervorhebenDate : 06/12/2016 10:21:16

I don't get what that means. An inventory of local linkages can be "drawn" (acquired?), as in your case study, from the expert-based interpretation of a geomorphological map.

I think there is a need for a (numerical) framework to appraise local (single landform, single linkage) and global (components, overall structure) properties of sediment cascades. Graph theory represents such a framework.

As Heckmann et al. (2015) put it: "With respect to structural graph analyses, explorations of scale linkage (...) are possible using graph theory that were not previously analytically tractable.

**As suggested, the sentence has been rephrased to highlight that graph theory is an efficient framework to appraise both local (i.e; "local links") and global (i.e. "catchment") scales**

Number: 5 Author: reviewer Subject: Eingefügter Text Date : 06/12/2016 10:16:05

Assess

**This was corrected accordingly**

Number: 6 Author: reviewer Subject: Notiz Date : 06/12/2016 10:22:38

using the classification proposed here, your study represents a spatially explicit analysis, as your nodes and edges are defined by spatial objects, and distances play a role.

**This was corrected accordingly**

Number: 7 Author: reviewer Subject: HervorhebenDate : 06/12/2016 10:08:26

Author: reviewer Subject: Notiz Date : 06/12/2016 10:08:33

formed?

**This was corrected accordingly It was a mistranslation from French**

Number: 8 Author: reviewer Subject: HervorhebenDate : 06/12/2016 10:12:24

at first, these indices address structure only. In theory, structure is surely related to "behaviour" (i.e. reaction to and propagation of change, efficiency of sediment transfer through the syste,), but how remains to be shown ! Especially as long as functional aspects (e.g. different transport rates implemented as edge attributes, c.f. comment by Rafael) are not accounted for, the effect on "behaviour" can be assessed only theoretically.

**You're right, this indices do not actually assess the behavior but the "skeleton of the sedimentary cascade in both space and time". The sentence was modified to better fit the objectives of the paper.**

Number: 9 Author: reviewer Subject: HervorhebenDate : 06/12/2016 10:14:28

interpret monitoring ? In my opinion, indices could help to assess consequences of what we monitor, e.g. the delivery of sediments. This would be more like "predicting" rather than "interpreting".

We agree. This **was corrected accordingly**

Number: 10 Author: reviewer Subject: HervorhebenDate : 06/12/2016 10:15:41

we propose such a connectivity index

Number: 11 Author: reviewer Subject: Notiz Date : 06/12/2016 10:23:56

you could specify these applications here (scenario analysis related to dis- and reconnection).

Number: 12 Author: reviewer Subject: Eingefügter Text Date : 06/12/2016 10:29:15

the proposed

**The last paragraph of the introduction was re-written to address comments 10, 11 and 12**

## Page 3

Number: 1 Author: reviewer Subject: Notiz Date : 06/12/2016 10:25:46

was that really a study of connectivity ? To me, it's a study that dealt with a phenomenon emerging from (dis-)connectivity, or a consequence of (dis-)connectivity.

**This was corrected as you suggested: “pointed out a problem that arises from (dis)connectivity”**

Number: 2 Author: reviewer Subject: Notiz Date : 06/12/2016 10:29:48

not always and everywhere !

**The first paragraph was rephrased to address comments 1 and 2**

Number: 3 Author: reviewer Subject: HervorhebenDate : 06/12/2016 10:28:11

In Baartman et al. (2013), for example, the SDR is sort of a proxy measure for connectivity, not connectivity itself.

Hoffmann (2015) wrote that "In its easiest form the SDR represents a black box model, without any further information on the processes that take place between the source and the outlet. In this respect, the SDR has been interpreted as a simple ‘performance’ factor to relate measured erosion at the plot scale to observed sediment yields at the larger scale. Its usefulness has been critically discussed during the past decades"
suggest to implement Hoffmann's discussion/terminology here, there is also criticism of the SDR concept.

**The SDR definition was rephrased with more accuracy according to this comment. The Hoffmann’s reference was also added.**

Number: 4 Author: reviewer Subject: Eingefügter Text Date : 06/12/2016 10:28:55

whose / the quantification of which

**This was corrected accordingly**

Number: 5 Author: reviewer Subject: Durchstreichen Date : 06/12/2016 10:29:58

**This was corrected accordingly**

Number: 6 Author: reviewer Subject: Durchstreichen Date : 06/12/2016 10:29:49

**This was corrected accordingly**

Number: 7 Author: reviewer Subject: Notiz Date : 06/12/2016

I would suggest to use W and S with a line on top (as in the original publication) to better distinguish between "mean weight" and "weight at a cell i". The readability would be increased if you use i in the index, i.e. as a subscript, as in the original paper.
Moreover, I am not sure whether it is necessary to report Borselli's/Cavalli's index at such detail here. If you decide to do so, you should point out the similarities/differences compared to your index (that also relates to up- and downslope linkages), and about potential amendments to your index (by accounting for slope and/or roughness). This would justify the degree of detail here.

**We decided to keep such a degree of detail here since we now refer a bit more on this index in the discussion of the manuscript (please see discussion on P 14 & 15)**

Number: 8 Author: reviewer Subject: HervorhebenDate : 06/12/2016 10:35:22

subscript, like in eq.2

**corrected**

Number: 9 Author: reviewer Subject: HervorhebenDate : 06/12/2016 10:36:13

place on the sigma, not behind it

I'd like to suggest using a formula editor (or formula notation in tex) here

**We modified using the formula editor**

## Page 4

Number: 1 Author: reviewer Subject: HervorhebenDate : 06/12/2016 10:37:50

high roughness is seen as impeding sediment transfer.

**This was corrected accordingly**

Number: 2 Author: reviewer Subject: Notiz Date : 06/12/2016 10:38:57

units are false, IC is dimensionless, see Marco's comment

**This was corrected accordingly and a new reference suggested by Marco Cavalli was added**

Number: 3 Author: reviewer Subject: HervorhebenDate : 06/12/2016 10:38:31

subscript

**This was corrected accordingly**

Number: 4 Author: reviewer Subject: HervorhebenDate : 06/12/2016 10:38:23

subscript

**This was corrected accordingly**

Number: 5 Author: reviewer Subject: Notiz Date : 06/12/2016 10:41:30

nodes and links are already graph theoretical terms. Consider rephrasing:
...to model the network structure as nodes (representing sediment sources, stores, and the outlet) connected by edges (representing linkages by
a geomorphic process)

**We rephrased accordingly**

Number: 6 Author: reviewer Subject: Notiz Date : 06/12/2016 10:42:07

I don't think the pattern has to be simple in order to be tractable with network analysis

**We agree. “Simple” was removed.**

Number: 7 Author: reviewer Subject: HervorhebenDate : 06/12/2016 10:42:33

pls specify what that means

**We rephrased to be clearer**

Number: 8 Author: reviewer Subject: HervorhebenDate : 06/12/2016 10:42:57

only possible when fluxes are quantified, right ?

**True, which is not the case here. We changed “influence the net contribution” to “estimate the potential influence”**

Number: 9 Author: reviewer Subject: Eingefügter Text Date : 06/12/2016 10:43:23

export ?

**corrected to transport**

Number: 10 Author: reviewer Subject: Eingefügter Text Date : 06/12/2016 10:43:31

s

**corrected**

Number: 11 Author: reviewer Subject: Eingefügter Text Date : 06/12/2016 10:43:43

s

**corrected**

Number: 12 Author: reviewer Subject: Eingefügter Text Date : 06/12/2016 10:43:53

Whose

**Corrected**

Number: 13 Author: reviewer Subject: Eingefügter Text Date : 06/12/2016 11:02:04

and/or (degree can be specified as total degree, or in- and out-degree, respectively)

**corrected**

Number: 14 Author: reviewer Subject: Notiz Date : 06/12/2016 13:57:34

"connected component" refers to the "overall" structure of a graph, please use the definition as used in the literature. You could expand here on some graph-theoretic components and their geomorphological meaning: For example, "if a node can contribute to the outlet", it would belong to the in-neighbourhood of the outlet node. Hanging valleys would form connected components with some coupling within the hanging valley but with no sediment export to the main valley. Or the main valley is divided in two components by a natural dam decoupling the lower section from the upper. Etc...

**The connected component has been defined in page 6 line 24. Here we have rephrased the sentence to evoke an “independent subcascade”.**

Number: 15 Author: reviewer Subject: HervorhebenDate : 06/12/2016 13:26:29

what is the "preferential location" of a type of nodes, e.g. of a sink ?
I think that both the spatial/topological configuration of the network and the fluxes associated with the respective edges are responsible for sediment delivery at the outlet.

**We rephrased as suggested to be clearer**

Number: 16 Author: reviewer Subject: Notiz Date : 06/12/2016 13:28:28

as Rafael already pointed out, there are several studies that make use of a network structure to model sediment fluxes, investigating e.g. the timing of sediment waves.
Examples:

Czuba, J.A., Foufoula-Georgiou, E., 2014. A network-based framework for identifying potential synchronizations and amplifications of sediment delivery in river basins. Water Resour. Res. 50, 3826-3851.

Czuba, J.A., Foufoula-Georgiou, E., 2015. Dynamic connectivity in a fluvial network for identifying hotspots of geomorphic change. Water Resour. Res. 51, 1401-1421.

Gran, K.B., Czuba, J.A., 2017. Sediment pulse evolution and the role of network structure. Geomorphology 277, 17-30.

**These references have been integrated to the paper and we now discuss the timing of sediment waves**

Number: 17 Author: reviewer Subject: Durchstreichen Date : 06/12/2016 13:32:30

**Corrected**

Number: 18 Author: reviewer Subject: Durchstreichen Date : 06/12/2016 13:32:21

**Corrected**

Number: 19 Author: reviewer Subject: HervorhebenDate : 06/12/2016 13:51:57

Please define the network effect;
what is meant by "it" ?
The network effect describes how... ?

**This is now more clearly defined. Please see P 5 L 7/8.**

Number: 20 Author: reviewer Subject: Notiz Date : 06/12/2016 13:52:00

...this is an assumption that is fairly unrealistic in a geomorphic system where storage landforms are built up - may be true though on the very long time scale. See discussion in Hoffmann (2015):

Hoffmann, T., 2015. Sediment residence time and connectivity in non-equilibrium and transient geomorphic systems. Earth-Science Reviews.

**While unrealistic, it is a hypothesis for a further simulation. But as in all simulation procedure, a simplification is required. Here, such a simplification seeks at exhibiting the specific role of spatial structure of the network (Gran & Czuba, 2015). It is now mentioned in the text.**

# Page 5

Number: 1 Author: reviewer Subject: Durchstreichen Date : 06/12/2016 13:57:52

**corrected**

Number: 2 Author: reviewer Subject: Notiz Date : 06/12/2016 13:52:26

and in geomorphology - see the Czuba & Foufoula-Georgiou papers

**corrected, we added 2 references Czuba & Foufoula-Georgiou 2014 and 2015**

Number: 3 Author: reviewer Subject: Durchstreichen Date : 06/12/2016 13:58:30

**corrected**

Number: 4 Author: reviewer Subject: Notiz Date : 06/12/2016 13:59:32

examples ? can these be used for geomorphological research problems ? Especially considering that sediment cascades form directed graphs ?

**We added the reference Rodrigue (2017). Undirected graph tools can be adapted to directed graphs. (see P 5 L 3/5) Geographers who worked on undirected graphs were some pioneers and it is of prime importance to cite their work. If we well understand how they worked, then we can avoid many difficulties regarding the formalization of spatial networks.**

Number: 5 Author: reviewer Subject: HervorhebenDate : 06/12/2016 14:00:12

what is "signification"

**It was a mistranslation from French. This was corrected accordingly**

Number: 6 Author: reviewer Subject: Eingefügter Text Date : 06/12/2016 13:58:40

Were

**corrected**

Number: 7 Author: reviewer Subject: Notiz Date : 06/12/2016 14:00:23

give references for the indices you present here

**We added the reference Rodrigue (2017).**

Number: 8 Author: reviewer Subject: HervorhebenDate : 06/12/2016 14:03:05

I don't think so - unless you assume that every path has the same flux, and that there is only convergent flow, i.e. fluxes are not dispersed from one node to more than one downslope neighbour.

**You are right, every path is considered to have the same flux. This corresponds to classical procedure of “flow analysis” in graph theory (Gleyze, 2008). It is a complex-reduced simulation to exhibit the role of the confluences within the network (fluxes are here only convergent).**

Number: 9 Author: reviewer Subject: HervorhebenDate : 06/12/2016 14:04:00

? don't understand what that means

**It has been rephrased**

Number: 10 Author: reviewer Subject: Notiz Date : 06/12/2016 14:04:18

give a reference for this criticism

**We added Rodrigue (2017)**

Number: 11 Author: reviewer Subject: Notiz Date : 06/12/2016 14:04:47

in what respect should eccentric nodes be "discriminated" ?

**The term is ambiguous. We have rephrased as following “ranking the influence of eccentric nodes”**

Number: 12 Author: reviewer Subject: Durchstreichen Date : 06/12/2016 14:05:51

Number: 13 Author: reviewer Subject: HervorhebenDate : 06/12/2016 16:02:06

?? Do you mean they should be ranked with respect to their importance or something like that ?

**Some sentences of the paragraph were modified to address comments 11, 12 and 13.**

Number: 14 Author: reviewer Subject: Notiz Date : 06/12/2016 16:05:16

in order to do this, edge attributes can be used as "cost".
Czuba et al. use properties of the edges to estimate the velocity of sediment transfer, etc...

**We agree, and it is now mentioned in the text.**

But why expand on these measures in undicrected graphs, when it is clear that we need directed graphs to represent sediment cascades ?

**As previously written, geographers who worked on undirected graphs were some pioneers and it is of prime importance to cite their**

**work. If we well understand how the worked, then we can avoid many difficulties regarding the formalization of spatial network.**

Number: 15 Author: reviewer Subject: HervorhebenDate : 06/12/2016 16:00:41

Ecentricity is a node property (precisely the distance from a node to the farthest other node in the network, please give reference for the definition), so I wonder how a node can minimise (= make as small as possible) or generate its own property !?

**The term eccentricity is also sometimes used to characterize the whole network. To avoid any ambiguity, the sentence has been rephrased.**

Number: 16 Author: reviewer Subject: Durchstreichen Date : 06/12/2016 16:01:05

**corrected**

Number: 17 Author: reviewer Subject: Durchstreichen Date : 06/12/2016 16:01:12

**corrected**

Number: 18 Author: reviewer Subject: Eingefügter Text Date : 06/12/2016 16:02:40 s

**corrected**

# Page 6

Number: 1 Author: reviewer Subject: Notiz Date : 06/12/2016 16:04:38

consider rephrasing:

a system (a cascading system in terms of Chorley & Kennedy) is a model representation of processes in nature. A network is a way to conceptualise such a system.

**We rephrased to address the comment**

Number: 2 Author: reviewer Subject: Durchstreichen Date : 06/12/2016 16:04:43

**corrected**

Number: 3 Author: reviewer Subject: Notiz Date : 06/12/2016 16:06:00

Its adjacency matrix is depicted in Tab. 1.

**Sentence added**

Number: 4 Author: reviewer Subject: Notiz Date : 06/12/2016 16:06:55

to assess how... ?

I think the "network effect" should be explained, can't be assumed to be well known among readers.

**The network effect is now defined (see P 5 L 8/9/10)**

Number: 5 Author: reviewer Subject: HervorhebenDate : 06/12/2016 16:06:16

Number: 6 Author: reviewer Subject: Notiz Date : 06/12/2016 16:12:24

what is meant by "extent" ?

Equation 7 is equal to Equation 5, with n replaced by F, and k by o.

You need to explain the difference, specifically what is F (flux rate ?). If F is a flux rate, Fijo is not "the extent to which i lies on paths..." but the proportion of fluxes passing through i related to all fluxes reaching o.

**rephrased**

Number: 7 Author: reviewer Subject: HervorhebenDate : 06/12/2016 16:07:59

Number: 8 Author: reviewer Subject: Eingefügter Text Date : 06/12/2016 16:12:29

i.e.

**corrected**

Number: 9 Author: reviewer Subject: Notiz Date : 06/12/2016 16:13:00

missing references here as well

**The reference Gran and Czuba (2015) was added.**

Number: 10 Author: reviewer Subject: Notiz Date : 06/12/2016 16:13:49

unit packet... ?

**We added unit**

Number: 11 Author: reviewer Subject: Notiz Date : 06/12/2016 16:26:24

you need to give references for these

equations. For example:
Schwanghart, W., Kuhn, N.J., 2010. TopoToolbox: A set of Matlab functions for topographic analysis. Environmental Modelling & Software 25, 770-781.

**Sorry but the reference is not well suited as we didn't used this tool.**

I don't think we need eq. 8 as eq. 9 is the generalised form that implies that it is applied iteratively (until all sediment is evacuated).

**We kept only eq. 9 as you suggested**

Number: 12 Author: reviewer Subject: HervorhebenDate : 06/12/2016 16:18:34

Number: 13 Author: reviewer Subject: Notiz Date : 06/12/2016 16:19:17

why not just write that eq.9 is applied iteratively ? "S." does not show up in the remaining text...

**We kept only eq. 9 as you suggested**

Number: 14 Author: reviewer Subject: Notiz Date : 06/12/2016 16:26:24

really ? I think that the graph itself shows the potential flows; with the representation of Sn you can show where the sediment is located (for each node), so whether there is a concentration or a depletion.

**We precised the employed terminology as it seems that confusion arise from an improper use of the term "flow" instead of "flux".**

Number: 15 Author: reviewer Subject: HervorhebenDate : 06/12/2016 16:20:32

Number: 16 Author: reviewer Subject: Notiz Date : 06/12/2016 16:21:08

please specify what that means, and give an example. Personally, I would prefer to see this discussed (with examples and references) in the discussion section.

**This has been moved to the results section and discussed with more details.**

Number: 17 Author: reviewer Subject: HervorhebenDate : 06/12/2016 16:40:25

specify what that means !

**Useful for defining a local monitoring strategy please see section 4.1.1**

Number: 18 Author: reviewer Subject: Eingefügter Text Date : 06/12/2016 16:21:23

of

**corrected**

Author: reviewer Subject: Eingefügter Text Date : 06/12/2016 16:21:33

Of **corrected**

Number: 20 Author: reviewer Subject: Notiz Date : 06/12/2016 16:21:59

...and there's only converging flow !

**This is the main hypothesis. Please see response to comment P5 N8**

Number: 21 Author: reviewer Subject: Eingefügter Text Date : 06/12/2016 16:22:18

at **corrected**

Number: 22 Author: reviewer Subject: Eingefügter Text Date : 06/12/2016 16:24:27

one ?

the ? **corrected (one)**

Number: 23 Author: reviewer Subject: Notiz Date : 06/12/2016 16:24:01

You need to better connect this text to Fig. 1, referring also to the Fig. parts A, B, and C ! The "flow index" that is mentioned in the caption for 1C is not even mentioned in the text.

**This has been addressed**

# Page : 7

Number: 1 Author: reviewer Subject: Eingefügter Text Date : 06/12/2016 16:33:52

S

**corrected**

Number: 2 Author: reviewer Subject: Eingefügter Text Date : 06/12/2016 16:25:29

these ?

**corrected**

Number: 3 Author: reviewer Subject: Notiz Date : 06/12/2016 16:26:21

I don't understand that - if you cut off the last node before the outlet (which is far from sources), you cut off almost the whole catchment...

**One main criticism expressed by geomorphologists is that connectivity does not directly reflect and explain the amount of sediments delivered at the outlet: the zone of highest connectivity is not the zone that contributes at maximum to the sediment delivery at the outlet. The connectivity indeed reveals more complex mutual interferences between all components of the system and consequently the**

**potential of geomorphic system to react. In other terms, the connectivity framework does not focus on the absolute values of sediment discharge but on signals. Studies on connectivity may predict how various signals (e.g. climatic signals, sedimentary signals at various points within catchment) can be propagated throughout the system. While it seems to divert geomorphologists from an important issue (assessing sediment balance), such a perspective is stimulating. Indeed, we can understand why sedimentary signals may reveal a "sedimentological anarchy". We particularly discussed that point in the discussion.**

Number: 4 Author: reviewer Subject: Eingefügter Text Date : 06/12/2016 16:24:45

the

**corrected**

Number: 5 Author: reviewer Subject: HervorhebenDate : 06/12/2016 16:28:01

I can't understand how a node can minimise (i.e. "make small") a distance. Either it IS far away or it IS close...

**This has been clarified: "The central hypothesis is that a node whose distance between the sediment sources and the outlet is minimal has a greater influence on the overall sediment cascade."**

Number: 6 Author: reviewer Subject: Eingefügter Text Date : 06/12/2016 16:27:00

(discriminated)

Assessed

**corrected**

Number: 7 Author: reviewer Subject: Notiz Date : 06/12/2016 16:33:52

please re-phrase that; sorry for not being able to follow.

Do you mean a node that is BOTH close to the outlet and close to sources is most significant for sediment transfer ? If so, why ?

**Please see P 7 L 5/8.**

Number: 8 Author: reviewer Subject: HervorhebenDate : 06/12/2016 16:30:35

nodes can't disrupt I think. What can be disrupted is an edge between two nodes.

In graph theory papers experimenting with changes in system structure, either nodes are removed, or edges. In the geomorphological case, it makes sense to disrupt an edge (when two adjacent nodes are no longer coupled)

**We agree! It is more consistent with these terms**

Number: 9 Author: reviewer Subject: Eingefügter Text Date : 06/12/2016 16:30:41

of the

**corrected**

Number: 10 Author: reviewer Subject: Notiz Date : 06/12/2016 16:31:41

better use other symbol, because in 3, you used A for the adjacency matrix...

Schwanghart & Kuhn, for example, use M as the symbol for the (flow direction)/adjacency matrix.

**We changed and now use "Shi"**

Number: 11 Author: reviewer Subject: Notiz Date : 06/12/2016 16:36:28

I don't think it is a good idea to use full stops as symbols.

Please try to use the same notation as, for example, a text book (and add the corresponding reference, see earlier comments)

**We kept this format as it is commonly used for distance matrices in the literature**

Number: 12 Author: reviewer Subject: HervorhebenDate : 06/12/2016 16:43:41

why "enhance" ? "highlights" ?

Where D.i is zero, Ai will be small. And for i close to the outlet, Di. will be small as well.

Is Ai supposed to increase for high accessibility ? Please define what accesibility is and how Ai is interpreted. And especially discuss how "accessibility" translates into connectivity-related properties.

**To address this comment we added the following sentence on P6 L13/14 "Nevertheless, we should point out that the lower the Shimbel index, the higher the accessibility (and thus the connectivity) of the nodes: while counterintuitive, this feature is now well accepted within the scientific community (Rodrigue, 2017)."**

Number: 13 Author: reviewer Subject: Notiz Date : 06/12/2016 22:15:35

so by smaller Ai, right ?

If so, the interpretation of Ai is contraintuitive (higher accessibility signified by lower Ai)... Needs to be checked and stated explicitly if correct.

**Please see previous reply**

Number: 14 Author: reviewer Subject: HervorhebenDate : 06/12/2016 16:46:50

why is the role of the outlet underestimated ? What is the role of the outlet (except being the outlet) ?

For nodes close to the outlet, Di. is very small, and I understood that small Ai translates into "high accessibility"...

**In terms of connectivity, the outlet is far from the sediment sources. Consequently D.i is at its maximum, and the accessibility is quite low.**

I am also confused by "the coupling between various pathways inside the sediment cascade". What does that mean ? Confluence of multiple pathways ? Divergence from a single node to multiple downslope neighbours ? Please be more specific and/or give an example.

**Yes, confluence of multiple pathways**

Number: 15 Author: reviewer Subject: HervorhebenDate : 06/12/2016 16:47:26

what does "exhibited" mean in this context ?

**Shown**

Number: 16 Author: reviewer Subject: Notiz Date : 06/12/2016 16:48:13

again, a node can't minimise a distance in my opinion.
Its distance to sources/sinks can be small, and maybe be the smallest compared to the other nodes. Is that what you mean ?

**Please see P9 L 27**

Number: 17 Author: reviewer Subject: Notiz Date : 06/12/2016 16:49:16

now explicitly discuss the implications of Fi and Ai for connectivity, and deduce why you compute Fi/Ai as a connectivity index.

**Please see P 8 L 7/12**

Number: 18 Author: reviewer Subject: HervorhebenDate : 06/12/2016 16:49:55

with distance from sources ?

**Corrected**

Nombre: 19 Auteur: reviewer Sujet: Eingefügter Text Date : 06/12/2016 16:50:01

include ?

**Corrected**

Nombre: 20 Auteur: reviewer Sujet: Eingefügter Text Date : 06/12/2016 16:50:13

contributing ?

**Corrected**

Nombre: 21 Auteur: reviewer Sujet: Notiz Date: 06/12/2016 16:55:27

be more specific. Make clear(er) that you use the "flow index" (?) to estimate the "expected" increase of discharge with distance from sources. What I don't understand now is why dividing Fi by Ai allows you to estimate whether Fi under- or overestimates the potential sediment volume. Please explain !

**Please see modifications on section 3.3.**

# Page 8

Number: 1 Author: reviewer Subject: Notiz Date : 06/12/2016 16:58:25

Is that something we did not already know (i) from looking at the graph and (ii) from routing the sediment downslope ? If the error(s) in Fig 1B are corrected, D and E will have the greatest values...

**The errors in Fig. 1B corresponded to a drawing mistake when we edited the figures: the calculations were right, and the other results do not have to be corrected.**

Number: 2 Author: reviewer Subject: Notiz Date : 06/12/2016 17:04:42

you address D and E as conductors/link nodes. Is the erosion rate on D and E so important then ? Or is it the erosion rate within their upslope contributing area !?

**Connectivity does not directly reflect and explain the amount of sediments delivered at the outlet: the zone of highest connectivity is not the zone that contributes at maximum to the sediment delivery at the outlet. The connectivity indeed reveals more complex mutual interferences between all components of the system and consequently the potential of geomorphic system to react.**

Number: 3 Author: reviewer Subject: Durchstreichen Date : 06/12/2016 17:04:44

**corrected**

Number: 4 Author: reviewer Subject: Notiz Date : 06/12/2016 16:59:50

...so connectivity would change fundamentally, and the change for nodes downstream of the outlet would be the same, right ?

**Yes**

Number: 5 Author: reviewer Subject: Durchstreichen Date : 06/12/2016 17:05:05

**corrected**

Number: 6 Author: reviewer Subject: Notiz Date : 06/12/2016 17:01:45

Explain why this is the case (in the model vs. in reality). In reality, the longer the distance, the longer the time, and the higher the probability of intermediate storage.

**Yes. Consequently, G is very close to the outlet: a geomorphic event in G would directly create an impact at the outlet. We have rephrased.**

Number: 7 Author: reviewer Subject: Eingefügter Text Date : 06/12/2016 17:02:39

The

**corrected**

Number: 8 Author: reviewer Subject: Eingefügter Text Date : 06/12/2016 17:02:53

and the

**corrected**

Number: 9 Author: reviewer Subject: Durchstreichen Date : 06/12/2016 17:05:57

**corrected**

Number: 10 Author: reviewer Subject: Eingefügter Text Date : 06/12/2016 17:05:55

Particular

**corrected**

Number: 11 Author: reviewer Subject: Notiz Date : 06/12/2016 17:06:28

...by changing the non-zero values to...

**Sorry, but we do not understand this comment.**

Number: 12 Author: reviewer Subject: Notiz Date : 06/12/2016 17:09:35

I don't agree. Distance and friction influence the travel time independently:
The longer the distance, the longer will it take for a sediment packet to reach the next node. The friction on that edge influences the "travel velocity" of the sediment.
C.f. Czuba & Foufoula-Georgiou (2014,2015). Moreover, one could argue that friction promotes (intermediate) storage, what will decrease the SDR.

**Yes, we agree and it has been rephrased and discussed in the discussion section. The distance is here estimated to approximate the travel time.**

Number: 13 Author: reviewer Subject: Notiz Date : 06/12/2016 22:03:00

Cavalli et al. (2013) use topographic roughness on a high-resolution DEM (standard deviation of residual topography), not the Manning coefficient; Baartman et al. (2013) used a much coarser DEM (30 m resolution), on which a comparable roughness index cannot be computed; they use a very simple roughness index (slope_max-slope_min within a 300x300 m moving window)...

**Corrected**

Number: 14 Author: reviewer Subject: Durchstreichen Date : 06/12/2016 22:03:15

**corrected**

# Page 9

Number: 1 Author: reviewer Subject: HervorhebenDate : 06/12/2016 22:09:02

write "B" in subscript to better indicate that it is F for node
B (FD, FE, FF in line 2f, and throughout the following
paragraph)

**corrected**

Number: 2 Author: reviewer Subject: Eingefügter Text Date : 06/12/2016 22:04:23

whose / the influence of which

**corrected**

Number: 3 Author: reviewer Subject: HervorhebenDate : 06/12/2016 22:07:30

can you really say if an increase by 0.03 is significant ? An increase of 0.02 (from 0.05 to 0.07) was not called significant... I think such a statement can only be made if a more thorough sensitivity analysis is conducted.

**Yes, a sensitivity analysis would be relevant but would require a specific paper. To be clearer and more simple here we differentiate nodes whose connectivity increases and nodes whose connectivity decreases.**

Number: 4 Author: reviewer Subject: Eingefügter Text Date : 06/12/2016 22:04:38

whose / the influence of which

**corrected**

Number: 5 Author: reviewer Subject: Eingefügter Text Date : 06/12/2016 22:09:53

S

**corrected**

Number: 6 Author: reviewer Subject: HervorhebenDate : 06/12/2016 22:10:46

Does that mean that Ai decreases (meaning higher accessibility !?) or that accessibility decreases (which would be signified by increasing Ai !?) ?

**This point has been clarified: "The accessibility coefficient decreases significantly" please see P11 L2**

Number: 7 Author: reviewer Subject: Notiz Date : 06/12/2016 22:17:48

but that's almost trivial considering that the topological distance between A and F is shorter (by one) than that between B and F...

**While trivial, this assertion is needed to fully interpret the results of the indices.**

Number: 8 Author: reviewer Subject: Eingefügter Text Date : 06/12/2016 22:18:08

S

**corrected**

Number: 9 Author: reviewer Subject: HervorhebenDate : 06/12/2016 22:25:11

why does a node property (great centrality) minimise a distance ?
The distance may control this property, not the other way round, right ?
Consider rephrasing please.

**This has been rephrased**

Number: 10 Author: reviewer Subject: Eingefügter Text Date : 06/12/2016 22:23:50

that are (?)

**corrected**

Number: 11 Author: reviewer Subject: HervorhebenDate : 06/12/2016 22:26:16

this is only for the didactic example, right ? In nature, the distance would not increase (roughness/impedance could, increase of course)

**Yes of course! You are right.**

Number: 12 Author: reviewer Subject: Eingefügter Text Date : 06/12/2016 22:26:28

S

**corrected**

Number: 13 Author: reviewer Subject: HervorhebenDate : 06/12/2016 22:27:35

see above comments... a node will not make a distance smaller. It has a small or great distance.

**Yes, we rephrased to be less ambiguous: "D here appears as a node of high connectivity as it is close to two main sources and to the outlet" see P11L12/13**

Number: 14 Author: reviewer Subject: Eingefügter Text Date : 06/12/2016 22:29:18

Increases

**corrected**

Number: 15 Author: reviewer Subject: Notiz Date : 06/12/2016 22:30:28

here you could discuss the similarity / difference related to Borselli's index, that would justify the detailed description of the latter in chapter 2.

**As the manuscript structure has changed, the comparison with broselli's index in now evoked in the discussion section.**

Number: 16 Author: reviewer Subject: Notiz Date : 06/12/2016 22:39:17

it could be discussed whether an index reflecting more process-related properties (e.g. by including roughness, traveltimes, slopes or similar edge properties, or sediment availability as a node property) may at least partially adress functional connectivity; especially if it was strongly correlated to SDR (that is seen as a proxy/performance measure of functional connectivity).

**It has been added within the discussion, and a reference (Reulier et al., 2016) is cited.**

Number: 17 Author: reviewer Subject: Eingefügter Text Date : 06/12/2016 22:39:36

whose / the functioning of which

**corrected**

Number: 18 Author: reviewer Subject: Notiz Date : 06/12/2016 22:41:18

I suggest that you give a short overview of topographic, climatological and lithological properties (a table might be enough).

**We added a short overview of the geomorphological context of the study area please see 4.2.1**

Number: 19 Author: reviewer Subject: Eingefügter Text Date : 06/12/2016 22:39:53

that is

**corrected**

# Page 10

Number: 1 Author: reviewer Subject: Notiz Date : 06/12/2016 22:45:05

the two scenarios are most significant where the system is close to such changes, i.e. where such changes are likely to happen. You could justify your choice of scenarios along these lines.

**The choice of scenarios is now better explained. They correspond to the most significant drop in terms of connectivity**

Number: 2 Author: reviewer Subject: Notiz Date : 06/12/2016:

the spatial pattern of these nodes is arranged in a way that the distance between nodes is not always 100m (only for cardinal neighbours), for some adjacent nodes the distance is 141 m (diagonal neighbours). Has this been accounted for ? It should, I think, because distance has been shown to be important in the calculation of the IC.

**No, it was not accounted see p9 l1/3**

Number: 3 Author: reviewer Subject: Notiz Date : 06/12/2016 22:51:50

does this expertise refer to every single instance, based on your field knowledge ? Or does it refer to a more general knowledge (related to landform types rather than specific cases), i.e. the fact that a lateral moraine forms a buffer ? Did you use diagnostic features to identify coupling in each case ?

**As explained in the text, it refers to a geomorphic expertise, already published in peer-review journals (Cossart and Fort, 2008; Cossart, 2016).**

Number: 4 Author: reviewer Subject: Eingefügter Text Date : 06/12/2016 22:49:59

ological

**corrected**

Number: 5 Author: reviewer Subject: Notiz Date : 06/12/2016 22:53:08

Here you could investigate the number and size of connected components, i.e. groups of nodes that form a sediment cascade but are disconnected from other cascades.

**This is now presented, especially in the new version of fig 7.**

Number: 6 Author: reviewer Subject: Notiz Date : 06/12/2016 23:04:39

(1) check the definition of barriers and buffers. In my opinion barriers refer to longitudinal (i.e. along the channel network) connectivity, while buffers refer to lateral connectivity (by decoupling hillslope-bourne sediment fluxes from the channel network). It might not apply to the specific landforms you name here.

**The definition have been changed and moraines can be buffers or barriers. Frontal moraines are good examples of barriers. It has been rephrase to avoid any ambiguity.**

(2) a morainic ridge surely is a buffer to lateral sediment flux. On the other hand, the same morainic ridge can be a source of sediment (it is dissected by fluvial incision and debris flows). How is that dealt with ?

Is there a single node connected both to upslope and downslope landforms ? Is the upslope cascade interrupted on the landform just upslope of the morainic ridge ?

**Yes, the node that corresponds to the upper part of the moraine is a sink, the node corresponding to the downslope part is a source. It is now specified.**

Number: 7 Author: reviewer Subject: Notiz Date : 06/12/2016 23:06:00

Fig 5B only clearly shows moraines as buffers (and as sources - at least it could be interpreted from the arrow with "22")

**This figure was revisited and integrated to the figure 7. We assume this is now clearer for the reader.**

Number: 8 Author: reviewer Subject: Notiz Date : 06/12/2016 23:08:56

important literature that also refers to connectivity:

Fryirs, K.A., 2016. River sensitivity. A lost foundation concept in fluvial geomorphology. Earth Surf. Process. Landforms, n/a-n/a.

**Ref. added**

Number: 9 Author: reviewer Subject: Eingefügter Text Date : 06/12/2016 23:09:13

propagate?

**corrected**

Number: 10 Author: reviewer Subject: Notiz Date : 06/12/2016 23:11:18

this conclusion is comparatively trivial and is not derived from the IC computation but directly from the graph structure that has been set up by a geomorphologist. The IC is used for ranking connectivity, not for assessing an "on-off"-state...

**Yes IC does not assess an on-off state. Geomorphic expertise helps at identifying where disconnections occur, and then graph theory assesses the size of the created connected components. As you mentioned before, the description of connected components is of prime importance to predict the influence of the structure on potential sediment fluxes.**

Number: 11 Author: reviewer Subject: Eingefügter Text Date : 06/12/2016 23:11:39

subcatchment

**corrected**

Number: 12 Author: reviewer Subject: Notiz Date : 06/12/2016 23:12:30

predicting the downstream transfer and delivery of sediment fluxes measured at one point ?

**corrected**

Number: 13 Author: reviewer Subject: Notiz Date : 06/12/2016 23:14:40

which is a hypothesis that you can't prove by computing an index that implements our theoretical understanding of a geomorphic system. Validation of such an index would require the assessment of the reaction to / propagation of change in relation to the index...

**Sensitivity analysis is forecasted and will be the topic of a single paper. At present we interpret more cautiously this point.**

Number: 14 Author: reviewer Subject: Durchstreichen Date : 06/12/2016 23:15:05

**corrected**

Number: 15 Author: reviewer Subject: Eingefügter Text Date : 06/12/2016 23:15:33

**corrected**

Number: 16 Author: reviewer Subject: Eingefügter Text Date : 06/12/2016 23:15:56

of scenarios

**corrected**

# Page 11

Number: 1 Author: reviewer Subject: Eingefügter Text Date : 06/12/2016 23:16:01

scenarios

**corrected**

Number: 2 Author: reviewer Subject: Eingefügter Text Date : 06/12/2016 23:16:13

of

**corrected**

Number: 3 Author: reviewer Subject: Durchstreichen Date : 06/12/2016 23:16:24

Number: 4 Author: reviewer Subject: Notiz Date : 06/12/2016 23:18:25

(1) why did you remove a node ? Wouldn't it be more meaningful to remove an edge ?

**We agree that it is more consistent to formulate this way (we disconnect a node, which means removing an edge…). Corrected.**

(2) how was the location of this disconnection chosen ? Deliberately or randomly ? I'd suggest to choose a location where such a disconnection is likely (same applies for the re-connection, lines 12ff)

**Deliberately (the most significant drop in terms of connectivity). It is now explained in the text.**

Number: 5 Author: reviewer Subject: Eingefügter Text Date : 06/12/2016 23:16:33

was removed

**Corrected**

Number: 6 Author: reviewer Subject: Eingefügter Text Date : 06/12/2016 23:16:37

A

**Corrected**

Number: 7 Author: reviewer Subject: Notiz Date : 06/12/2016 23:19:22

i.e. the formation of a new connected component ?

**Yes. The section has been entirely rephrased.**

Number: 8 Author: reviewer Subject: HervorhebenDate : 06/12/2016 23:19:01

a node (or better: edge) is disrupted, it does not disrupt

**Corrected**

Number: 9 Author: reviewer Subject: Eingefügter Text Date : 06/12/2016 23:19:36

fed by (?)

**Corrected**

Number: 10 Author: reviewer Subject: Notiz Date : 06/12/2016 23:22:52

suggest to add the change effected by the scenario (a decrease from 60% to 26%)

**The change effect was added**

Number: 11 Author: reviewer Subject: Notiz Date : 06/12/2016 23:25:40

...well, but the consequences in terms of SDR would remain the same, right ?
So it remains questionable why two different changes in connectivity (as measured by IC) should lead to the same consequences.
Conversely,
how valuable is an index that would not predict a change in sediment delivery because two different values would be associated with the same
delivery ?
This is a conceptual/theoretical issue you need to discuss.

**One main criticism expressed by geomorphologists is that connectivity does not directly reflect and explain the amount of sediments delivered at the outlet: the zone of highest connectivity is not the zone that contributes at maximum to the sediment delivery at the outlet. The connectivity indeed reveals more complex mutual interferences between all components of the system and consequently the potential of geomorphic system to react. In other terms the connectivity framework does not focus on the absolute values of sediment discharge but on signals. Studies on connectivity may predict how various signals (e.g. climatic signals, sedimentary signals at various points within catchment) can be propagated throughout the system. While it seems to divert geomorphologists from an important issue (assessing sediment balance), such a perspective is stimulating. Indeed, we can understand why sedimentary signals may reveal a "sedimentological anarchy". We particularly discussed that point in the discussion.**

Number: 12 Author: reviewer Subject: Notiz Date : 06/12/2016 23:27:02

here, you add a new edge (not a new node), what makes more sense to me. Consider changing your first scenario accordingly.

**We agree that it is more consistent to formulate this way (we connect a new node, which means adding a new edge…). Corrected.**

Number: 13 Author: reviewer Subject: Durchstreichen Date : 06/12/2016 23:25:53

**Corrected**

Number: 14 Author: reviewer Subject: Durchstreichen Date : 06/12/2016 23:26:03

**Corrected**

Number: 15 Author: reviewer Subject: Eingefügter Text Date : 06/12/2016 23:27:30

large

**Corrected**

Number: 16 Author: reviewer Subject: Eingefügter Text Date : 06/12/2016 23:29:45

in this scenario

**Corrected**

Number: 17 Author: reviewer Subject: Notiz Date : 06/12/2016 23:29:29

why ?
This "why" has two aspects:(1) why does the index change (a numerical issue)
(2) is it plausible that connectivity really changes with this scenario (a geomorphological issue)

**What we explain here is that if we re-connect a sub-catchment (that was previously disconnected), it affects the whole catchment connectivity since the relative influence (contribution) of each sub-basin will be modified.**

Number: 18 Author: reviewer Subject: Eingefügter Text Date : 06/12/2016 23:30:11

T

**Corrected**

Number: 19 Author: reviewer Subject: Notiz Date : 06/12/2016 23:30:33

changes of

**Corrected**

Number: 20 Author: reviewer Subject: Eingefügter Text Date : 06/12/2016 23:30:39

the

**Corrected**

Number: 21 Author: reviewer Subject: Eingefügter Text Date : 06/12/2016 23:30:52

Enables

**Corrected**

Number: 22 Author: reviewer Subject: Eingefügter Text Date : 06/12/2016 23:31:01

...between (sub-)catchments ?

**Corrected**

Number: 23 Author: reviewer Subject: Notiz Date : 06/12/2016 23:34:08

do the data really justify the conclusion that the index is robust (i.e. insensitive to minor changes in parameters) ?? And is such robustness required for the index to be used in comparative studies?
The Borselli index has issues of comparability because it depends on the size of the contributing area - similar scale-dependence could arise for your IC index, because the number of edges is somehow related to the size of the contributing area.
Reconsider and discuss!

**The sentence here has been modified to be more balanced: "the IC enables comparisons between different states of connectivity within the same catchment.". Additionally, we discuss the robustness if the index in discussion and note that transposition to other study sites is necessary.**

Number: 24 Author: reviewer Subject: Durchstreichen Date : 06/12/2016 23:34:35

**Corrected**

Number: 25 Author: reviewer Subject: Eingefügter Text Date : 06/12/2016 23:34:32

the influence of

**Corrected**

# Page 12

Number: 1 Author: reviewer Subject: Eingefügter Text Date : 06/12/2016 23:40:23

implemented

**Corrected**

Number: 2 Author: reviewer Subject: Eingefügter Text Date : 06/12/2016 23:40:32

x

**Corrected**

Number: 3 Author: reviewer Subject: HervorhebenDate : 06/12/2016 23:40:51

Terminology

**Corrected**

Number: 4 Author: reviewer Subject: HervorhebenDate : 06/12/2016 23:41:24

??

**Practical applications**

# Page 17

Nombre: 1 Auteur: reviewer Sujet: Notiz Date: 06/12/2016 23:44:57

if ali the nades contain and pass on sediments, A B G O, D E 2, and C FI(which is consistent with table 2
In FiglB,C and E have the wrong amount of sediment after 1 iteration.
Could it be that the "flow index" (not named in the text) in IC is wrong as weil? Please double-check, in ali Figures and tables.

**The errors in Fig. 1B corresponded to a drawing mistake when we edited the figures: the calculations and tables are right, and the other results do not have to be corrected**

# Page 19

Nombre 1 Auteur: reviewer sujet: Notiz Date : 06/12/2016 23 :06 :21

(1) Missing units
(2) The numbers in SB are not addressed (not even mentioned) in the text.
A few lines in the text on the geomorphological map SA (and its main features) could also help.

**The figure 5 has been modified. This figure (now fig. 6) is now only showing the geomorphological map. The pattern of potential flow is now in the next figure (with the units) for each of the scenarios. A geomorphological description of the area has been added in the text.**

# Page 20

Nombre 1 Auteur: reviewer sujet: Notiz Date : 06/12/2016 23 :06 :21

scale bar is missing

**Corrected**

different length of diagonal vs. cardinal linkages presumably not accounted for => needs to be addressed

**It is already addressed in the text. We used a topologic distance (i.e. All links = 1). It must be more explicit in this second version of the**

**paper.**

Consider evaluating the number and size of decoupled "connected components", i.e. those subcascades that are not connected to the outlet (not graphically, but in the text)
**It has been done.**

Earth Surf. Dynam. Discuss., doi:10.5194/esurf-2016-55, 2016
Manuscript under review for journal Earth Surf. Dynam.
Published: 8 November 2016


# Assessment of structural sediment connectivity within catchments: insights from graph theory

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**Abstract.** To understand the sedimentary signal delivered at catchment outlets, many authors now refer to the concept of connectivity. In this framework, the sedimentary signal is seen as an emergent organization of local filiations and interactions. The challenge is then to open black boxes that remain within a sediment cascade, that requires both accurate geomorphic investigations in the field (reconstruction of sequences of geomorphic evolution, description of sediment pathways) but also the development of tools dedicated to sediment cascades modelling. More precisely the development of tools dedicated to the study of connectivity in geomorphology is still in progress, even if the graph theory offers promising perspectives (Heckmann and Schwanghart, 2013). In this paper, graph theory is applied to abstract the network structure of sediment cascades, keeping only nodes (sediment sources, sediment stores, outlet) and links (linkage by a transportation agent), represented as vertices and edges. From the description of the assemblages of sedimentary flows, we provide three main indices to explore how small-scale processes may result in significant broad-scale geomorphic patterns. First, we assess the potential contribution of each node to the sediment delivery at the outlet. Second, we measure the influence of each node regarding how this node is accessible from both sediment sources and outlet. Third, we calculate a connectivity index to reveal whether the potential contribution of a node is lower or higher than expected from its location within the network. These indices are calculated in the case of a virtual sediment cascade, but are also applied to a catchment located in southern french alps. We demonstrate that these indices are robust, and may lead to simulations. In the present case, we try to predict how a sediment cascade may be impacted by a node disruption or by a reconnection.

## 1 Introduction

The concept of connectivity provides now an overarching framework in geosciences to better explore the functioning of catchments. Connectivity has been first defined in ecology to assess the spatial coherence of a system of landscape elements, a coherence that is necessary to maintain or restore ecological functions (Bennett, 2004). Following these pioneering discussions, it has been increasingly used by hydrologists to model hydrological connections patterns (Delahaye et al., 2001; Douvinet et al., 2008); Ali and Roy (2009) for instance summarize that hydrological connectivity can be seen as a function of available water volume (calculated from a hydrological balance) and the rate of transfer. More recently, connectivity has appeared as a fruiftul conceptual framework in geomorphology (Brierley et al., 2006; Wainwright et al., 2011; Fryirs, 2013):

# Résumé des commentaires sur esurf-2016-55-RC1-supplement-1.pdf

## Page : 1

Nombre : 1 Auteur : reviewer Sujet : HervorhebenDate : 06/12/2016 10:01:23

Auteur : reviewer Sujet : Notiz Date : 06/12/2016 10:05:29
this is a bit cryptic, especially "filiations"; please stick to the terminology accepted systems- and connectivity-related literature

it helps in studying the spatio-temporal unsteadiness of sediment transport within catchments, and why sediment cascades can be considered a "jerky conveyor belt" (Ferguson, 1981). Unsteadiness patterns in sediment transfers are indeed one main field of research for geomorphologists, and refer to the "spatial and temporal paradox" exhibited by McGuiness et al. (1971): in a catchment, sediment delivery from sources on hillslopes is not correlated with sediment delivery at the outlet. Consequently, sediment cascades are not necessarily efficient to transfer sediments, highlighting a "sediment delivery problem" (Walling, 1983). Finally, geomorphic signals, especially sediment delivery, cannot be interpreted easily (e.g. in terms of climate change, anthropogenic influences, etc.) and may much more reveal a "sedimentological anarchy" (Walker, 1990; Bravard, 1998; Schumm, 2005): at catchment scale geomorphic processes may be coupled to create a sediment impulse, or may be antagonistic to create a blockage, alternately.

Recently, many authors asked for complex-systems approach to conceptualize the continuum of sediment transfer: how processes at local scales may be combined to understand the functioning of the whole sediment cascade (Fryirs et al., 2007; Borselli et al., 2008; Fryirs, 2013; Bracken et al., 2015). Such a multiscalar framework has been conceptualized by Heckmann and Schwanghart (2013) who have clearly distinguished the coupling of processes, and connectivity. On the one hand geomorphic coupling is "the linkage of distinct landforms or landscape units by sediment transport" (Harvey, 2001), it refers to "elementary interactions at the relatively small scale" (Faulkner, 2008). On the other hand "the degree of coupling, the combined effect of lateral (hillslope to channel) and longitudinal (from one river reach to another) linkages between system components, is termed (sediment) connectivity" (Heckmann and Schwanghart, 2013). Shifting from the local to the catchment scale remains a main issue to well explain how small-scale measurements of erosion result in broad-scale geomorphic patterns and processes (Bracken et al., 2015). It requires the development of numerical methods to draw exhaustive inventory of all the local linkages within the sediment cascades, to exhibit their properties, and then to predict the result of their combination. One promising field of research has been opened up by the application of graph theory, that offers mathematical tools to analyse statistically and spatially the assemblages of all the components of a sediment cascade (Heckmann and Schwanghart, 2013; Heckmann et al., 2015). This methodological framework particularly focuses on the structural connectivity, i.e. the influence of the spatial patterns drawn by the linkages on sediment delivery. One main objective is to provide a quantitative index that would help in comparing the geomorphic behaviour of catchments in both space and time. It would also allow an estimation of the contribution of a given part of the catchment to provide sediments at the outlet, and to interpret local erosion monitoring (Cavalli et al., 2013).

In this paper we seek at assessing such a connectivity index. Following a brief state-of-art regarding connectivity indices, we explore the main mathematical tools provided by graph theory to measure the structural sediment connectivity within a catchment. Then we look at the main applications and interpretations of connectivity index.

# Page : 2

Nombre : 1 Auteur : reviewer Sujet : Durchstreichen Date : 06/12/2016 10:03:31

Nombre : 2 Auteur : reviewer Sujet : Eingefügter Text Date : 06/12/2016 10:04:02
a

Nombre : 3 Auteur : reviewer Sujet : HervorhebenDate : 06/12/2016 10:08:23
Measurements don't lead to processes !
Suggestion: ...how erosion and sediment transfer on a small spatial scale interact to form broad-scale geomorphic patterns and processes.

Nombre : 4 Auteur : reviewer Sujet : HervorhebenDate : 06/12/2016 10:21:16
I don't get what that means. An inventory of local linkages can be "drawn" (acquired?), as in your case study, from the expert-based interpretation of a geomorphological map.
I think there is a need for a (numerical) framework to appraise local (single landform, single linkage) and global (components, overall structure) properties of sediment cascades. Graph theory represents such a framework.

As Heckmann et al. (2015) put it: "With respect to structural graph analyses, explorations of scale linkage (...) are possible using graph theory that were not previously analytically tractable.

Nombre : 5 Auteur : reviewer Sujet : Eingefügter Text Date : 06/12/2016 10:16:05
assess

Nombre : 6 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 10:22:38
using the classification proposed here, your study represents a spatially explicit analysis, as your nodes and edges are defined by spatial objects, and distances play a role.

Nombre : 7 Auteur : reviewer Sujet : HervorhebenDate : 06/12/2016 10:08:26

Auteur : reviewer Sujet : Notiz Date : 06/12/2016 10:08:33
formed?

Nombre : 8 Auteur : reviewer Sujet : HervorhebenDate : 06/12/2016 10:12:24
at first, these indices address structure only. In theory, structure is surely related to "behaviour" (i.e. reaction to and propagation of change, efficiency of sediment transfer through the syste,), but how remains to be shown ! Especially as long as functional aspects (e.g. different transport rates implemented as edge attributes, c.f. comment by Rafael) are not accounted for, the effect on "behaviour" can be assessed only theoretically.

Nombre : 9 Auteur : reviewer Sujet : HervorhebenDate : 06/12/2016 10:14:28
interpret monitoring ? In my opinion, indices could help to assess consequences of what we monitor, e.g. the delivery of sediments. This would be more like "predicting" rather than "interpreting".

Nombre : 10 Auteur : reviewer Sujet : HervorhebenDate : 06/12/2016 10:15:41
we propose such a connectivity index

Nombre : 11 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 10:23:56
you could specify these applications here (scenario analysis related to dis- and reconnection).

Nombre : 12 Auteur : reviewer Sujet : Eingefügter Text Date : 06/12/2016 10:29:15
the proposed

Earth Surf. Dynam. Discuss., doi:10.5194/esurf-2016-55, 2016
Manuscript under review for journal Earth Surf. Dynam.
Published: 8 November 2016


## 2 State-of-art

By stating that catchments are inefficient at supplying sediment to the outlet, Walling (1983) developed one pioneering study of catchments sediment connectivity. He exhibited that they are characterized by a low sediment delivery ratio (SDR).

SDR = Vh / Vo  (1)

Where Vh is the volume of sediment eroded from hillslopes and Vo is the volume of sediment delivered at the outlet of the catchment. The SDR is a synthetic index that assesses the connectivity of a catchment, and allows comparisons in both space and time. Recently, it has for instance been demonstrated that SDR (and connectivity) decreases with increasing landscape morphological complexity (Baartman et al., 2013). One main criticism regarding this index is that catchments remain a black box: no attention is paid to the geomorphic linkages involved at local scale, nor to the feedbacks between geomorphic processes (Gumiere et al., 2011; Fryirs, 2013).

To open such black boxes, the concept of connectivity has been subdivided in two distinct parts (With et al., 1997; Tischendorf and Fahrig, 2000; Turnbull et al., 2008). On the one hand the structural connectivity refers to spatial patterns in the landscape, such as the spatial distribution of landscape units which influences sediment transfer patterns and sediment paths. On the other hand, the functional connectivity focuses on how geomorphic processes may activate or block the sediment transfer along the spatial links within the sediment cascade (Kimberly et al., 1997; With and King, 1997; Belisle, 2005; Uezu et al., 2005). The latter is now also often called process-based sediment connectivity and has been documented in depth in a recent review (Bracken et al., 2015). Here we focus on the structural connectivity, ~~which~~ quantification is required for exploring and understanding the responses of geomorphic systems (Wainwright et al., 2011).

### 2.1 Structural sediment connectivity

Following Borselli et al. (2008), Cavalli et al. (2013) developed a connectivity index (Eq. 2) that ~~cell~~ refers to the structural connectivity. It estimates that connectivity at one location within the catchment can be seen as a ratio between an upslope (Eq. 3) and a downslope components (Eq. 4):

$$IC = \log_{10}\left(\frac{D_{up}}{D_{dn}}\right) \quad (2)$$

$D_{up} = W S \sqrt{A}$  (3)

$D_{dn} = \sum di / Wi\ Si$  (4)

where W is the average weighting factor of the upslope contributing area, S is the average slope gradient of the upslope contributing area (m/m) and A is the upslope contributing area (m2) and where di is the length of the flow path along the ith cell according to the steepest downslope direction (m), Wi and Si are the weighting factor and the slope gradient of the ith cell, respectively. In Borselli et al. (2008) the weighting factor W first corresponded to the C-factor of USLE-RUSLE models (Wischmeier and Smith 1978; Renard et al. 1997) to refer to frictions that hinder the sediment transfer. More

Nombre : 1 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 10:25:46

was that really a study of connectivity ? To me, it's a study that dealt with a phenomenon emerging from (dis-)connectivity, or a consequence of (dis-)connectivity.

Nombre : 2 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 10:29:48

not always and everywhere !

Nombre : 3 Auteur : reviewer Sujet : HervorhebenDate : 06/12/2016 10:28:11

In Baartman et al. (2013), for example, the SDR is sort of a proxy measure for connectivity, not connectivity itself.

Hoffmann (2015) wrote that "In its easiest form the SDR represents a black box model, without any further information on the processes that take place between the source and the outlet. In this respect, the SDR has been interpreted as a simple 'performance' factor to relate measured erosion at the plot scale to observed sediment yields at the larger scale. Its usefulness has been critically discussed during the past decades"
suggest to implement Hoffmann's discussion/terminology here, there is also criticism of the SDR concept.

Nombre : 4 Auteur : reviewer Sujet : Eingefügter Text Date : 06/12/2016 10:28:55

whose / the quantification of which

Nombre : 5 Auteur : reviewer Sujet : Durchstreichen Date : 06/12/2016 10:29:58

Nombre : 6 Auteur : reviewer Sujet : Durchstreichen Date : 06/12/2016 10:29:49

Nombre : 7 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 10:35:04

I would suggest to use W and S with a line on top (as in the original publication) to better distinguish between "mean weight" and "weight at a cell i". The readability would be increased if you use i in the index, i.e. as a subscript, as in the original paper.

Moreover, I am not sure whether it is necessary to report Borselli's/Cavalli's index at such detail here. If you decide to do so, you should point out the similarities/differences compared to your index (that also relates to up- and downslope linkages), and about potential amendments to your index (by accounting for slope and/or roughness). This would justify the degree of detail here.

Nombre : 8 Auteur : reviewer Sujet : HervorhebenDate : 06/12/2016 10:35:22

subscript, like in eq.2

Nombre : 9 Auteur : reviewer Sujet : HervorhebenDate : 06/12/2016 10:36:13

place on the sigma, not behind it

I'd like to suggest using a formula editor (or formula notation in tex) here

Earth Surf. Dynam. Discuss., doi:10.5194/esurf-2016-55, 2016
Manuscript under review for journal Earth Surf. Dynam.
Published: 8 November 2016




recently, it has been demonstrated that topographic surface roughness can provide a good estimation of the weighting factor (Cavalli et al., 2013; Baartman et al., 2013): great topographic heterogeneity impeding sediment transfer. This index opens up a fruitful field of research to assess the structural connectivity. First, it opens the black boxes within a catchment: the IC index can be calculated for each cell of the catchment, highlighted what are the cells that may highly contribute to the sediment flux at the outlet. Second, this index takes into account all the links that exist between a cell and all other components of the catchment: it nicely refers to the definition of connectivity. Third, the index can be mapped so that it allows comparisons between various locations (a specific tool has been developped in Arc GIS), and furthermore to calculate maps of connectivity evolution through time. Nevertheless, this index remains empiric, so that comparisons between catchments should be made carefully. More specifically, the units used during the calculation make the interpretation of the results complicated. Dup is indeed calculated in meters, Ddn is calculated in meters-1, so that IC is expressed in m2.

Another promising field of research refers to the application of graph theory that provides a robust mathematical framework for describing networks such as sediment cascades (Heckmann and Schwanghart, 2013; Heckmann et al., 2015; Cossart, 2016). Graph theory is applied to abstract the network structure, keeping only nodes (sediment sources, sediment stores, outlet) and links (linkage by a transportation agent), represented as vertices and edges. The goal is to get a simple pattern that can be described by algebraic tools (typology of linkages, identification of local sinks, etc.) to exhibit the overall structure of the sedimentary cascade. Graph theory enables to describe objectively the assemblages of sedimentary flows, and thus to estimate the net contribution of the network to the amount of sediment load. Indices provided by graph theory were hitherto developed to characterize the properties of single landscape units (nodes), sediment pathways (edges) and sediment cascades (edge sequences = paths). The nodes can be characterized by the number and type of links that may provide or ~~carry out~~ sediments. Sediment sources are characterized by the lack of input link; sinks are characterized by no output link; and other nodes correspond to connectors, ~~which~~ importance is revealed by their degree (number of input ~~and~~ output links). The links may be characterized by the geomorphic process that carries sediments. Regarding the edge sequences their main characteristic is whether they may contribute or not the sediment delivery at the outlet: do they correspond to a connected component or not? The frequency and the preferential location of each type of nodes, edges and edge sequences are of prime importance to explain the SDR at the outlet (Heckmann and Schwanghart, 2013; Heckmann et al., 2015).

One another application is to conduct some "flow analyses. In a directed graph (such as sediment cascades) each edge has a capacity and each edge receives a flow. A flow must satisfy the restriction that the amount of flow into a node equals the amount of flow out of it, unless it is a source, which has only outgoing flow, or sink, which has only incoming flow. This is a simulation~~, to the extent~~ that ~~this analysis~~ is based on an assumption of conservation of flow. In the case of sources having no incoming links, a default common value can be assigned to them. Sometimes called network effect (Pumain and Saint-Julien, 2010), it exhibits how the network structure predisposes and organizes sediment flows "all things being equal" (Cossart, 2016).

Nombre : 1 Auteur : reviewer Sujet : HervorhebenDate : 06/12/2016 10:37:50
high roughness is seen as impeding sediment transfer.

Nombre : 2 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 10:38:57
units are false, IC is dimensionless, see Marco's comment

Nombre : 3 Auteur : reviewer Sujet : HervorhebenDate : 06/12/2016 10:38:31
subscript

Nombre : 4 Auteur : reviewer Sujet : HervorhebenDate : 06/12/2016 10:38:23
subscript

Nombre : 5 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 10:41:30
nodes and links are already graph theoretical terms. Consider rephrasing:
...to model the network structure as nodes (representing sediment sources, stores, and the outlet) connected by edges (representing linkages by a geomorphic process)

Nombre : 6 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 10:42:07
I don't think the pattern has to be simple in order to be tractable with network analysis

Nombre : 7 Auteur : reviewer Sujet : HervorhebenDate : 06/12/2016 10:42:33
pls specify what that means

Nombre : 8 Auteur : reviewer Sujet : HervorhebenDate : 06/12/2016 10:42:57
only possible when fluxes are quantified, right ?

Nombre : 9 Auteur : reviewer Sujet : Eingefügter Text Date : 06/12/2016 10:43:23
export ?

Nombre : 10 Auteur : reviewer Sujet : Eingefügter Text Date : 06/12/2016 10:43:31
s

Nombre : 11 Auteur : reviewer Sujet : Eingefügter Text Date : 06/12/2016 10:43:43
s

Nombre : 12 Auteur : reviewer Sujet : Eingefügter Text Date : 06/12/2016 10:43:53
whose

Nombre : 13 Auteur : reviewer Sujet : Eingefügter Text Date : 06/12/2016 11:02:04
and/or (degree can be specified as total degree, or in- and out-degree, respectively)

Nombre : 14 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 13:57:34
"connected component" refers to the "overall" structure of a graph, please use the definition as used in the literature. You could expand here on some graph-theoretic components and their geomorphological meaning: For example, "if a node can contribute to the outlet", it would belong to the in-neighbourhood of the outlet node. Hanging valleys would form connected components with some coupling within the hanging valley but with no sediment export to the main valley. Or the main valley is divided in two components by a natural dam decoupling the lower section from the upper. Etc...

Nombre : 15 Auteur : reviewer Sujet : HervorhebenDate : 06/12/2016 13:26:29
what is the "preferential location" of a type of nodes, e.g. of a sink ?
I think that both the spatial/topological configuration of the network and the fluxes associated with the respective edges are responsible for sediment delivery at the outlet.

Nombre : 16 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 13:28:28
as Rafael already pointed out, there are several studies that make use of a network structure to model sediment fluxes, investigating e.g. the timing of sediment waves.
Examples:

Czuba, J.A., Foufoula-Georgiou, E., 2014. A network-based framework for identifying potential synchronizations and amplifications of sediment delivery in river basins. Water Resour. Res. 50, 3826-3851.

Czuba, J.A., Foufoula-Georgiou, E., 2015. Dynamic connectivity in a fluvial network for identifying hotspots of geomorphic change. Water Resour. Res. 51, 1401-1421.

Gran, K.B., Czuba, J.A., 2017. Sediment pulse evolution and the role of network structure. Geomorphology 277, 17-30.

Suite des commentaires de la page 4 sur la page suivante

Earth Surf. Dynam. Discuss., doi:10.5194/esurf-2016-55, 2016
Manuscript under review for journal Earth Surf. Dynam.
Published: 8 November 2016


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recently, it has been demonstrated that topographic surface roughness can provide a good estimation of the weighting factor (Cavalli et al., 2013; Baartman et al., 2013): a great topographic heterogeneity impeding sediment transfer. This index opens up a fruitful field of research to assess the structural connectivity. First, it opens the black boxes within a catchment: the IC index can be calculated for each cell of the catchment, highlighted what are the cells that may highly contribute to the sediment flux at the outlet. Second, this index takes into account all the links that exist between a cell and all other components of the catchment: it nicely refers to the definition of connectivity. Third, the index can be mapped so that it allows comparisons between various locations (a specific tool has been developped in Arc GIS), and furthermore to calculate maps of connectivity evolution through time. Nevertheless, this index remains empiric, so that comparisons between catchments should be made carefully. More specifically, the units used during the calculation make the interpretation of the results complicated. Dup is indeed calculated in meters, Dds is calculated in meters-1, so that IC is expressed in m2.

Another promising field of research refers to the application of graph theory that provides a robust mathematical framework for describing networks such as sediment cascades (Heckmann and Schwanghart, 2013; Heckmann et al., 2015; Cossart, 2016). Graph theory is applied to abstract the network structure, keeping only nodes (sediment sources, sediment stores, outlet) and links (linkage by a transportation agent), represented as vertices and edges. The goal is to get a simple pattern that can be described by algebraic tools (typology of linkages, identification of local sinks, etc.) to exhibit the overall structure of the sedimentary cascade. Graph theory enables to describe objectively the assemblages of sedimentary flows, and thus to estimate the net contribution of the network to the amount of sediment load. Indices provided by graph theory were hitherto developed to characterize the properties of single landscape units (nodes), sediment pathways (edges) and sediment cascades (edge sequences = paths). The nodes can be characterized by the number and type of links that may provide or carry out sediments. Sediment sources are characterized by the lack of input link; sinks are characterized by no output link; and other nodes correspond to connector which importance is revealed by their degree (number of input and output links). The links may be characterized by the geomorphic process that carries sediments. Regarding the edge sequences their main characteristic is whether they may contribute or not the sediment delivery at the outlet: do they correspond to a connected component or not? The frequency and the preferential location of each type of nodes, edges and edge sequences are of prime importance to explain the SDR at the outlet (Heckmann and Schwanghart, 2013; Heckmann et al., 2015).

One another application is to conduct some "flow analyses": in a directed graph (such as sediment cascades) each edge has a capacity and each edge receives a flow. A flow must satisfy the restriction that the amount of flow into a node equals the amount of flow out of it, unless it is a source, which has only outgoing flow, or sink, which has only incoming flow. This is a simulation the extent that this analysis is based on an assumption of conservation of flow. In the case of sources having no incoming links, a default common value can be assigned to them. Sometimes called network effect (Pumain and Saint-Julien, 2010), it exhibits how the network structure predisposes and organizes sediment flows "all things being equal" (Cossart, 2016).

Nombre : 17 Auteur : reviewer Sujet : Durchstreichen Date : 06/12/2016 13:32:30

Nombre : 18 Auteur : reviewer Sujet : Durchstreichen Date : 06/12/2016 13:32:21

Nombre : 19 Auteur : reviewer Sujet : HervorhebenDate : 06/12/2016 13:51:57

Please define the network effect;
what is meant by "it" ?
The network effect describes how... ?

Nombre : 20 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 13:52:00

...this is an assumption that is fairly unrealistic in a geomorphic system where storage landforms are built up - may be true though on the very long time scale. See discussion in Hoffmann (2015):

Hoffmann, T., 2015. Sediment residence time and connectivity in non-equilibrium and transient geomorphic systems. Earth-Science Reviews.

Earth Surf. Dynam. Discuss., doi:10.5194/esurf-2016-55, 2016
Manuscript under review for journal Earth Surf. Dynam.
Published: 8 November 2016


### 2.2 Structural connectivity indices in undirected graphs

The influence of the structure of a spatial network on material or immaterial fluxes has been deeply explored in case of transportation studies (Cole and King, 1968; Gleyze, 2008), social networks (Freeman, 1979) or more recently in ecology (Ludwig et al., 2002; Belisle, 2005). In such studies, one key requirement is to provide a hierarchy of the influence of nodes within the network. Nodes characterized by a high connectivity have indeed a considerable influence within a network as they control fluxes passing between many others. Such high connectivity nodes are also the ones where a disruption would imply the more dramatic damages on the network functioning (Haggett and Chorley, 1969; Newman, 2010). They indeed lie on the largest number of possible paths whithin the network. Many indices were calculated from the mathematical tools provided by graph theory and applied to undirected graphs. Their signification may nevertheless help in understanding how the structural connectivity can be measured in directed graphs such as sediment cascades.

First, the Betweenness centrality index (B) measures the extent to which a node i lies on paths between other nodes (Eq. 5):

Bi = ∑ nijk / njk (5)

where nijk is the number of paths that exist from a node j to a node k, and that pass through i; and where njk is the total number of paths that exist within the network, from j to k. This index provides a good evaluation of the potential volume that may pass through the nodes and is helpful for interpreting, even normalizing the real fluxes observed in each node of the network. One main criticism is that this index enhances the role of nodes close the centre of gravity of the network and is not really efficient in discriminating the eccentric nodes. However, such eccentric nodes are close to the sources, the entrances, of the network and should be discriminated between themselves. Furthermore, spatial patterns are taken into account in a simplistic way: the distance (and the friction effect of the distance to hinder fluxes) is not considered.

The Shimbel index (Shi) takes into account the distance between nodes and consider whether the location of the node generates or minimize eccentricity within the network (Eq. 6) (Newman, 2010). For one node i, it corresponds to the sum of the length of all shortest paths connecting all other nodes j in the graph (dij). To facilitate comparisons in both space and time, this index should be normalized, being divided by the sum of the length of all paths in the network, from j to k (djk).

Shii = ∑dij/∑djk (6)

On the one hand if the Shimbel index is high, then the node contributes to create long paths within the network (and thus attenuates the compactness of the network). On the other hand, if the Shimbel index is low, then the node maximizes the compactness of the network. This index is much more efficient to discriminate the influence of eccentric nodes on the network and can be enriched by considering various types of distance (geodesic, time, etc.). It is noted that the lower the Shimbel index, the higher the accessibility (and thus the connectivity) of the nodes.

Both indices allow a description in depth of the skeleton of a network, and highlight the potential impacts of network structure on the fluxes patterns. They can thus provide conceptual and mathematical frameworks to explore the structure of sediment cascades. Nevertheless they cannot be applied directly to measure sediment connectivity as sediment cascades are directed graphs, more complicated in terms of mathematical conceptualization.

# Page : 5

Nombre : 1 Auteur : reviewer Sujet : Durchstreichen Date : 06/12/2016 13:57:52

Nombre : 2 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 13:52:26
and in geomorphology - see the Czuba & Foufoula-Georgiou papers

Nombre : 3 Auteur : reviewer Sujet : Durchstreichen Date : 06/12/2016 13:58:30

Nombre : 4 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 13:59:32
examples ? can these be used for geomorphological research problems ? Especially considering that sediment cascades form directed graphs ?

Nombre : 5 Auteur : reviewer Sujet : HervorhebenDate : 06/12/2016 14:00:12
what is "signification"

Nombre : 6 Auteur : reviewer Sujet : Eingefügter Text Date : 06/12/2016 13:58:40
were

Nombre : 7 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 14:00:23
give references for the indices you present here

Nombre : 8 Auteur : reviewer Sujet : HervorhebenDate : 06/12/2016 14:03:05
I don't think so - unless you assume that every path has the same flux, and that there is only convergent flow, i.e. fluxes are not dispersed from one node to more than one downslope neighbour.

Nombre : 9 Auteur : reviewer Sujet : HervorhebenDate : 06/12/2016 14:04:00
? don't understand what that means

Nombre : 10 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 14:04:18
give a reference for this criticism

Nombre : 11 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 14:04:47
in what respect should eccentric nodes be "discriminated" ?

Nombre : 12 Auteur : reviewer Sujet : Durchstreichen Date : 06/12/2016 14:05:51

Nombre : 13 Auteur : reviewer Sujet : HervorhebenDate : 06/12/2016 16:02:06
?? Do you mean they should be ranked with respect to their importance or something like that ?

Nombre : 14 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 16:05:16
in order to do this, edge attributes can be used as "cost".
Czuba et al. use properties of the edges to estimate the velocity of sediment transfer, etc...

But why expand on these measures in undicrected graphs, when it is clear that we need directed graphs to represent sediment cascades ?

Nombre : 15 Auteur : reviewer Sujet : HervorhebenDate : 06/12/2016 16:00:41
Ecentricity is a node property (precisely the distance from a node to the farthest other node in the network, please give reference for the definition), so I wonder how a node can minimise (= make as small as possible) or generate its own property !?

Nombre : 16 Auteur : reviewer Sujet : Durchstreichen Date : 06/12/2016 16:01:05

Nombre : 17 Auteur : reviewer Sujet : Durchstreichen Date : 06/12/2016 16:01:12

Nombre : 18 Auteur : reviewer Sujet : Eingefügter Text Date : 06/12/2016 16:02:40
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Earth Surf. Dynam. Discuss., doi:10.5194/esurf-2016-55, 2016
Manuscript under review for journal Earth Surf. Dynam.
Published: 8 November 2016


## 3 Methods to assess structural connectivity

Sediment cascades can be described as systems and networks (Chorley and Kennedy, 1971; Schumm, 2005). In detail, they may be represented by directed graphs, where the nodes correspond to landscape units (sediment sources, stores or sink) and the edges to sediment pathways (Heckmann et al., 2015). Two nodes i and j are joined or adjacent if there is an edge from i to j. Suppose we are given a directed graph with n nodes, the graph can be represented by an n × n adjacency matrix A, constructed as follows: if there is an edge from node i to node j, then we put 1 as the entry on row i, column j of the matrix A. In this study we first consider a virtual sediment cascade, with 7 nodes (Fig. 1).

### 3.1 Potential flows in directed graphs

As in undirected graphs, one first issue is to quantify the "network effect" (sensu Pumain and Saint-Julien, 2010) to enhance how the spatial structure of paths influences the amount of sediments transferred to the outlet. In sediment cascades, only the paths that come from one node j to the outlet o are to be considered, so that in each node i we have to measure the extent to which i lies on paths from other nodes j to o (Fijo). This measurement is normalized, thus, divided by the total number of paths that come from all nodes j to o (Fjo) (Eq. 7).

$$F_i = \sum F_{ijo} / F_{jo} \quad (7)$$

Fijo and Fjo can be calculated by reconstructing the pathways of sediments throughout the cascade. Under the hypothesis of "all things being equal", a virtual volume of sediments 1 is set on each node. The evacuation of the sediments can be simulated by a matrix multiplication of the adjacency matrix with a matrix representing the sediment sources (S0) (Eq. 8). This matrix is a one column matrix, where each row represents a node of the cascade, 1 is put on each row to represent the virtual volume of sediments at the beginning of the transfer. Each multiplication corresponds to an iteration, in which each sediment is transferred along one edge, according to the links described by the adjacency matrix (Eq. 9) (table 1). The result provides a matrix S1, highlighting where are the sediments after one single iteration.

$$S1 = S0 \times A \quad (8)$$

$$Sn = Sn\text{-}1 \times A \quad (9)$$

The operation is repeated until all virtual sediments are evacuated, and the results can represented within a synthetic matrix (S.), concatenating S0, S1,…, Sn matrices obtained during the calculation (table 2). This operation finally provides a first map of the potential flows within the sediment cascade. Such a result can be useful for interpreting local monitoring of sediment transfer, and then for interpolating local measurements at the catchment scale. Moreover, this index may provide a hierarchy between the nodes by assessing the increase of sediments involved upstream and upstream the node. For instance, in our virtual study case, the amount of sediment classically increases downstream, as there is no interruption of the cascade. Nevertheless, the main increase occurs apart node D, pointing out that this node has a great influence on the functioning of the sediment cascade. Any disruption of this node (blockage due to an overflow of sediments, anthropogenic action, etc.) would significantly impact the ability of the cascade to deliver sediments at the outlet. Nevertheless, on main criticism is that

# Page : 6

Nombre : 1 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 16:04:38

consider rephrasing:

a system (a cascading system in terms of Chorley & Kennedy) is a model representation of processes in nature. A network is a way to conceptualise such a system.

Nombre : 2 Auteur : reviewer Sujet : Durchstreichen Date : 06/12/2016 16:04:43

Nombre : 3 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 16:06:00

Its adjacency matrix is depicted in Tab. 1.

Nombre : 4 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 16:06:55

to assess how... ?

I think the "network effect" should be explained, can't be assumed to be well known among readers.

Nombre : 5 Auteur : reviewer Sujet : HervorhebenDate : 06/12/2016 16:06:16

Nombre : 6 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 16:12:24

what is meant by "extent" ?
Equation 7 is equal to Equation 5, with n replaced by F, and k by o.
You need to explain the difference, specifically what is F (flux rate ?). If F is a flux rate, Fijo is not "the extent to which i lies on paths..." but the proportion of fluxes passing through i related to all fluxes reaching o.

Nombre : 7 Auteur : reviewer Sujet : HervorhebenDate : 06/12/2016 16:07:59

Nombre : 8 Auteur : reviewer Sujet : Eingefügter Text Date : 06/12/2016 16:12:29

i.e.

Nombre : 9 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 16:13:00

missing references here as well

Nombre : 10 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 16:13:49

unit
packet
... ?

Nombre : 11 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 16:26:24

you need to give references for these equations.
For example:
Schwanghart, W., Kuhn, N.J., 2010. TopoToolbox: A set of Matlab functions for topographic analysis. Environmental Modelling & Software 25, 770-781.

I don't think we need eq. 8 as eq. 9 is the generalised form that implies that it is applied iteratively (until all sediment is evacuated).

Nombre : 12 Auteur : reviewer Sujet : HervorhebenDate : 06/12/2016 16:18:34

Nombre : 13 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 16:19:17

why not just write that eq.9 is applied iteratively ?
"S." does not show up in the remaining text...

Nombre : 14 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 16:26:24

really ? I think that the graph itself shows the potential flows; with the representation of Sn you can show where the sediment is located (for each node), so whether there is a concentration or a depletion.

Nombre : 15 Auteur : reviewer Sujet : HervorhebenDate : 06/12/2016 16:20:32

Nombre : 16 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 16:21:08

please specify what that means, and give an example. Personally, I would prefer to see this discussed (with examples and references) in the discussion section.

Nombre : 17 Auteur : reviewer Sujet : HervorhebenDate : 06/12/2016 16:40:25

specify what that means !

Suite des commentaires de la page 6 sur la page suivante

Earth Surf. Dynam. Discuss., doi:10.5194/esurf-2016-55, 2016
Manuscript under review for journal Earth Surf. Dynam.
Published: 8 November 2016




### 3 Methods to assess structural connectivity

Sediment cascades can be described as systems and networks (Chorley and Kennedy, 1971; Schumm, 2005). In details, they may be represented by directed graphs, where the nodes correspond to landscape units (sediment sources, stores or sink) and the edges to sediment pathways (Heckmann et al., 2015). Two nodes i and j are joined or adjacent if there is an edge from i to j. Suppose we are given a directed graph with n nodes, the graph can be represented by an n × n adjacency matrix A, constructed as follows: if there is an edge from node i to node j, then we put 1 as the entry on row i, column j of the matrix A. In this study we first consider a virtual sediment cascade, with 7 nodes (Fig. 1).

### 3.1 Potential flows in directed graphs

As in undirected graphs, one first issue is to quantify the "network effect" (sensu Pumain and Saint-Julien, 2010) to enhance how the spatial structure of paths influences the amount of sediments transferred to the outlet. In sediment cascades, only the paths that come from one node j to the outlet o are to be considered, so that in each node i we have to measure the extent to which i lies on paths from other nodes j to o (Fijo). This measurement is normalized, thus subdivided by the total number of paths that come from all nodes j to o (Fjo) (Eq. 7).

$F_i = \sum F_{ijo} / F_{jo}$ (7)

Fijo and Fjo can be calculated by reconstructing the pathways of sediments throughout the cascade. Under the hypothesis of "all things being equal", a virtual volume of sediments 1 is set on each node. The evacuation of the sediments can be simulated by a matrix multiplication of the adjacency matrix with a matrix representing the sediment sources (S0) (Eq. 8). This matrix is a one column matrix, where each row represents a node of the cascade, 1 is put on each row to represent the virtual volume of sediments at the beginning of the transfer. Each multiplication corresponds to an iteration, in which each sediment is transferred along one edge, according to the links described by the adjacency matrix (Eq. 9) (table 1). The result provides a matrix S1, highlighting where are the sediments after one single iteration.

$S1 = S0 \times A$ (8)

$Sn = Sn\text{-}1 \times A$ (9)

The operation is repeated until all virtual sediments are evacuated, and the results can represented within a synthetic matrix (S.), concatenating S0, S1,…, Sn matrices obtained during the calculation (table 2). This operation finally provides a first map of the potential flows within the sediment cascade. Such a result can be useful for interpreting local monitoring of sediment transfer, and then for interpolating local measurements at the catchment scale. Moreover, this index may provide a hierarchy between the nodes by assessing the increase of sediments involved upstream and upstream to the node. For instance, in our virtual study case, the amount of sediment classically increases downstream, as there is no interruption of the cascade. Nevertheless, the main increase occurs apart from node D, pointing out that this node has a great influence on the functioning of the sediment cascade. Any disruption of this node (blockage due to an overflow of sediments, anthropogenic action, etc.) would significantly impact the ability of the cascade to deliver sediments at the outlet. Nevertheless, a main criticism is that

Nombre : 18 Auteur : reviewer Sujet : Eingefügter Text Date : 06/12/2016 16:21:23
of

Nombre : 19 Auteur : reviewer Sujet : Eingefügter Text Date : 06/12/2016 16:21:33
of

Nombre : 20 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 16:21:59
...and there's only converging flow !

Nombre : 21 Auteur : reviewer Sujet : Eingefügter Text Date : 06/12/2016 16:22:18
at

Nombre : 22 Auteur : reviewer Sujet : Eingefügter Text Date : 06/12/2016 16:24:27
one ?
the ?

Nombre : 23 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 16:24:01
You need to better connect this text to Fig. 1, referring also to the Fig. parts A, B, and C ! The "flow index" that is mentioned in the caption for 1C is not even mentioned in the text.

Earth Surf. Dynam. Discuss., doi:10.5194/esurf-2016-55, 2016
Manuscript under review for journal Earth Surf. Dynam.
Published: 8 November 2016


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this index pays little attention to the sediment sources (here A, B and G) while the events that happen on it may influence long pathways to the outlet. As evoked for betweenness index, it is necessary to better discriminate the potential influence of sources and stores located next to sources.

### 3.2 Accessibility from sources and to sinks

Within a sediment cascade, the influence of geomorphic units (sources, stores, sinks) on sediment delivery can be discriminating by considering their location inside the cascades. The main hypothesis is that a node minimizing the distance between both sediment sources and the outlet has a greater influence on the overall sediment cascade. In other words, if such strategic nodes disrupt, the ability of the cascade to deliver sediment would be significantly affected. Characterizing the nodes by their location within the network refers to the concept of accessibility (A) and is thus very similar to the calculation of Shimbel index in case of undirected graphs. In case of directed graphs, the calculation of the accessibility Ai of each node i can be made from a distance matrix D (Eq. 10) (table 3):

Ai = (D.i + Di.) / D.. (10)

Where D.i is the total of the distances between I and the nodes (sources and stores) that feed i, Di. is the distance between i and the nodes located downstream, and D.. is the total of the distances of all paths within the network. The main interest of this index is that it enhances the sources (where D.i equals 0), and more particularly the sources that minimize the distance to the outlet (Fig. 2). Here, G is characterized by the better accessibility, greater than A, greater than B. A hierarchy of the influence of sediment sources to sediment delivery at the outlet is thus provided. In terms of management, it highlights the sources that can be activated to cope with a sediment exhaustion at the outlet or, conversely, sources where protection strategies should be applied in case of sediment overflow. Nevertheless, this index is not a good proxy of connectivity as it underestimates the role of the outlet and all nodes close to the outlet, and does not pay attention to the coupling between various pathways inside the sediment cascade. At the catchment scale, the role of D and E is not exhibited while they are important connectors between pathways developed from sources A and B. It is necessary to compare carefully the index of both nodes to note that D minimizes more the distance to different sources and the outlet than E.

### 3.3 Combination of indices

The indices Fi and Ai provide a quantitative and complementary description of the sediment cascade skeleton, the first one revealing the potential increase of sediment discharge along the sediment paths, the second one measuring the eccentricity from the sources and the outlet. Classically, the sediment discharge increases with eccentricity from sources, as the paths lie across many nodes from which sediments can be supplied (i.e. the active area is higher). Nevertheless, due to the geometry of paths, of confluences, this increase of sediment discharge can be higher or lower than expected from the distance to sources. To estimate this possible under or overrepresentation of potential sediment volume in each node, a ratio between Fi and Ai can be calculated (Eq. 11):

ICi = Fi / Ai (11)

# Page : 7

Nombre : 1 Auteur : reviewer Sujet : Eingefügter Text Date : 06/12/2016 16:33:52
s

Nombre : 2 Auteur : reviewer Sujet : Eingefügter Text Date : 06/12/2016 16:25:29
these ?

Nombre : 3 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 16:26:21
I don't understand that - if you cut off the last node before the outlet (which is far from sources), you cut off almost the whole catchment...

Nombre : 4 Auteur : reviewer Sujet : Eingefügter Text Date : 06/12/2016 16:24:45
the

Nombre : 5 Auteur : reviewer Sujet : HervorhebenDate : 06/12/2016 16:28:01
I can't understand how a node can minimise (i.e. "make small") a distance. Either it IS far away or it IS close...

Nombre : 6 Auteur : reviewer Sujet : Eingefügter Text Date : 06/12/2016 16:27:00
(discriminated)
assessed

Nombre : 7 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 16:33:52
please re-phrase that; sorry for not being able to follow.
Do you mean a node that is BOTH close to the outlet and close to sources is most significant for sediment transfer ? If so, why ?

Nombre : 8 Auteur : reviewer Sujet : HervorhebenDate : 06/12/2016 16:30:35
nodes can't disrupt I think. What can be disrupted is an edge between two nodes.
In graph theory papers experimenting with changes in system structure, either nodes are removed, or edges. In the geomorphological case, it makes sense to disrupt an edge (when two adjacent nodes are no longer coupled)

Nombre : 9 Auteur : reviewer Sujet : Eingefügter Text Date : 06/12/2016 16:30:41
of the

Nombre : 10 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 16:31:41
better use other symbol, because in 3, you used A for the adjacency matrix...

Schwanghart & Kuhn, for example, use M as the symbol for the (flow direction)/adjacency matrix.

Nombre : 11 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 16:36:28
I don't think it is a good idea to use full stops as symbols.
Please try to use the same notation as, for example, a text book (and add the corresponding reference, see earlier comments)

Nombre : 12 Auteur : reviewer Sujet : HervorhebenDate : 06/12/2016 16:43:41
why "enhance" ? "highlights" ?
Where D.i is zero, Ai will be small. And for i close to the outlet, Di. will be small as well.
Is Ai supposed to increase for high accessibility ? Please define what accesibility is and how Ai is interpreted. And especially discuss how "accessibility" translates into connectivity-related properties.

Nombre : 13 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 22:15:35
so by smaller Ai, right ?
If so, the interpretation of Ai is contraintuitive (higher accessibility signified by lower Ai)... Needs to be checked and stated explicitly if correct.

Nombre : 14 Auteur : reviewer Sujet : HervorhebenDate : 06/12/2016 16:46:50
why is the role of the outlet underestimated ? What is the role of the outlet (except being the outlet) ?
For nodes close to the outlet, Di. is very small, and I understood that small Ai translates into "high accessibility"...

I am also confused by "the coupling between various pathways inside the sediment cascade". What does that mean ? Confluence of multiple pathways ? Divergence from a single node to multiple downslope neighbours ? Please be more specific and/or give an example.

Nombre : 15 Auteur : reviewer Sujet : HervorhebenDate : 06/12/2016 16:47:26
what does "exhibited" mean in this context ?

Nombre : 16 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 16:48:13
again, a node can't minimise a distance in my opinion.
Its distance to sources/sinks can be small, and maybe be the smallest compared to the other nodes. Is that what you mean ?

Nombre : 17 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 16:49:16
now explicitly discuss the implications of Fi and Ai for connectivity, and deduce why you compute Fi/Ai as a connectivity index.

Nombre : 18 Auteur : reviewer Sujet : HervorhebenDate : 06/12/2016 16:49:55

Suite des commentaires de la page 7 sur la page suivante

Earth Surf. Dynam. Discuss., doi:10.5194/esurf-2016-55, 2016
Manuscript under review for journal Earth Surf. Dynam.
Published: 8 November 2016


this index pay little attention to the sediment sources (here A, B and G) while the events that happen on ~~it~~ may influence long pathways to the outlet. As evoked for betweenness index, it is necessary to better discriminate the potential influence of sources and stores located next to sources.

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Ai = (D.i + Di.) / D.. (10)

Where D.i is the total of the distances between I and the nodes (sources and stores) that feed i, Di. is the distance between i and the nodes located downstream, and D.. is the total of the distances of all paths within the network. The main interest of this index is that it enhances the sources (where D.i equals 0), and more particularly the sources that minimize the distance to the outlet (Fig. 2). Here, G is characterized by the better accessibility, greater than A, greater than B. A hierarchy of the influence of sediment sources to sediment delivery at the outlet is thus provided. In terms of management, it highlights the sources that can be activated to cope with a sediment exhaustion at the outlet or, conversely, sources where protection strategies should be applied in case of sediment overflow. Nevertheless, this index is not a good proxy of connectivity as it underestimates the role of the outlet and all nodes close to the outlet, and does not pay attention to the coupling between various pathways inside the sediment cascade. At the catchment scale, the role of D and E is not exhibited while they are important connectors between pathways developed from sources A and B. It is necessary to compare carefully the index of both nodes to note that D minimizes more the distance to different sources and the outlet than E.

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ICi = Fi / Ai (11)

with distance from sources ?

Nombre : 19 Auteur : reviewer Sujet : Eingefügter Text Date : 06/12/2016 16:50:01

include ?

Nombre : 20 Auteur : reviewer Sujet : Eingefügter Text Date : 06/12/2016 16:50:13

contributing ?

Nombre : 21 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 16:55:27

be more specific. Make clear(er) that you use the "flow index" (?) to estimate the "expected" increase of discharge with distance from sources. What I don't understand now is why dividing Fi by Ai allows you to estimate whether Fi under- or overestimates the potential sediment volume. Please explain !

Earth Surf. Dynam. Discuss., doi:10.5194/esurf-2016-55, 2016
Manuscript under review for journal Earth Surf. Dynam.
Published: 8 November 2016




The results can be seen as a normalization of the potential sediment fluxes Fi (table 4). It is noticed that the most important nodes regarding IC are E and D (Fig. 3), with very similar values (0.8 and 0.71 respectively). E and D are at confluences and thus lie on various sediment paths organized from distinct sources: their potential influence on the whole sediment cascade is high, so that any disruption of these nodes would considerably alter the elementary interactions between many nodes and sediment paths. Consequently D and E may modify significantly the ability of the cascade to provide sediments and should be further studied in depth to document the functional connectivity, or to assess erosion rates (local monitoring, field observations). The outlet F has a quite high but lower index (0.66). This value reveals the high potential sediment volume that passes through this node but point out that any disruption at this node would be ambiguous. Indeed it would interrupt the sediment delivery, but the organization of the three sediment paths from sources A, B and G would be not modified, and the coupling patterns at the confluences would also remain unmodified. Finally, the structure of the cascade would be roughly unchanged. Regarding the sources (A, B and D): a hierarchy is evidenced. The source G has a greater influence on the sedimentary signal at the outlet thanks to its proximity (IC = 0.53), higher than A and B (IC equals 0.27 and 0.12, respectively).

**3.4 Index parameters**

IC index can be calculated from simple parameters: adjacency matrix (drawn from a geomorphic expertise), distance matrix. Nevertheless two main components of the equations can be parameterized to enrich the model, for instance to fit the index to the geomorphic purpose or to a management issue. First, regarding the assessment of Fi, all sources are assumed to be of equal importance (volume availability equals to 1). A geomorphic hierarchy of sources (in terms of sediment supply) can be parameterized, for instance if a source ~~particularly~~ overflows or, conversely, is exhausted: the matrix representing the sediment sources (S0) can then be adjusted. Second, the distance is an important parameter that can modify the results of Ai, and then ICi. Distance indeed creates a friction that hampers the sediment transfer: the higher the distance, the higher the friction opposed to sediment delivery. In the virtual study case, we considered a topological distance within the matrix to be simple. Many other kinds of distance can of course be taken into account: Euclidian distance for instance, but in geomorphology many other type of distance may be more relevant. A distance in time, to reveal the duration of transfer from one unit to another one can be particularly relevant, even difficult to assess. A cost distance should be also relevant, by revealing how hampered (or efficient) is the sediment transfer along the edge: a manning coefficient (Cavalli et al., 2013), or more generally a roughness index (Baartman et al., 2013) can be a good proxy of the friction that hampers the sediment transfer. Such parameters can be calculated from high-resolution DEM and then joined to the edges characteristics through GIS procedures.

To document how the indices are sensitive to the parameterization, we modify the initial conditions of our virtual sediment cascade (Fig. 4). Regarding sediment availability, we consider G exhausted (volume equals 0) and B overflowing (volume equals 2). All other nodes remain unchanged. Regarding the distance, the distance between E and F is now twice the initial value (DEF equals 2).

# Page : 8

Nombre : 1 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 16:58:25
Is that something we did not already know (i) from looking at the graph and (ii) from routing the sediment downslope ? If the error(s) in Fig 1B are corrected, D and E will have the greatest values...

Nombre : 2 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 17:04:42
you address D and E as conductors/link nodes. Is the erosion rate on D and E so important then ? Or is it the erosion rate within their upslope contributing area !?

Nombre : 3 Auteur : reviewer Sujet : Durchstreichen Date : 06/12/2016 17:04:44

Nombre : 4 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 16:59:50
...so connectivity would change fundamentally, and the change for nodes downstream of the outlet would be the same, right ?

Nombre : 5 Auteur : reviewer Sujet : Durchstreichen Date : 06/12/2016 17:05:05

Nombre : 6 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 17:01:45
Explain why this is the case (in the model vs. in reality). In reality, the longer the distance, the longer the time, and the higher the probability of intermediate storage.

Nombre : 7 Auteur : reviewer Sujet : Eingefügter Text Date : 06/12/2016 17:02:39
the

Nombre : 8 Auteur : reviewer Sujet : Eingefügter Text Date : 06/12/2016 17:02:53
and the

Nombre : 9 Auteur : reviewer Sujet : Durchstreichen Date : 06/12/2016 17:05:57

Nombre : 10 Auteur : reviewer Sujet : Eingefügter Text Date : 06/12/2016 17:05:55
particular

Nombre : 11 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 17:06:28
...by changing the non-zero values to...

Nombre : 12 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 17:09:35
I don't agree. Distance and friction influence the travel time independently:
The longer the distance, the longer will it take for a sediment packet to reach the next node. The friction on that edge influences the "travel velocity" of the sediment.
C.f. Czuba & Foufoula-Georgiou (2014,2015). Moreover, one could argue that friction promotes (intermediate) storage, what will decrease the SDR.

Nombre : 13 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 22:03:00
Cavalli et al. (2013) use topographic roughness on a high-resolution DEM (standard deviation of residual topography), not the Manning coefficient; Baartman et al. (2013) used a much coarser DEM (30 m resolution), on which a comparable roughness index cannot be computed; they use a very simple roughness index (slope_max-slope_min within a 300x300 m moving window)...

Nombre : 14 Auteur : reviewer Sujet : Durchstreichen Date : 06/12/2016 22:03:15

As expected, the potential flow Fi is mainly modified on B which influence increases (IB shifting from 0.05 to 0.07), and on G which influence becomes null. On other nodes, a significant increase is observed on D (FD shifting from 0.18 to 0.21) while FE and FF remain roughly unchanged. While the node D was already strategic in the first simulation, the increase of sediment availability on B reinforces its influence on the whole sediment cascade. Downstream, the potential flow on E and F is not reinforced by the amount of sediments delivered on B because of the exhaustion of G.

Considering the accessibility, the higher eccentricity of F has an impact on AF, but more generally alters the accessibility of all nodes. Accessibility decreases significantly on B: the subcascade organized from B is the longest and all the sediment paths that may exist along this subcascade are impacted by the friction between E and F. As a consequence, the outlet is here significantly less accessible from the source B than from the sources A and G (the latter remaining the closer). It is noticed that the accessibility of D is not impacted by the higher eccentricity of F: AD remains roughly stable, and even suggests slight improvement of the accessibility. All nodes characterized by a great centrality, and that may minimize the distances from both the sources and the outlet, are not affected by an increasing eccentricity at the margins of the cascade (if distance from sources, or at the outlet, increases).

Finally, regarding the connectivity index, the new parameterization have modified the hierarchy of nodes. First we note that the influence of the confluence nodes has increased: this pattern is particularly significant on D, a node of a high connectivity: it minimizes the distance to two main sources and to the outlet. The node E is also of prime importance, but its connectivity is quite lower than expected from its strategic location as it is connected to an exhausted source (G). Looking at the sources, a hierarchy is clearly observed: the influence of B gets higher due to its main contribution to the sediment flow, while the influence of G becomes null as it is exhausted.

The IC index thus reveals on each unit of a sediment cascade the degree of coupling to both the sources and the outlet. More precisely it reflects the structural connectivity as it enhances the role of spatial patterns (distance, confluences, etc.) of the network. In a simplistic way, it highlights how the network structure and the spatial patterns influence the sediment flows "all things being equal". The parameterization could moreover be progressively enriched thanks to a geomorphic expertise to pay more attention on sediment availability or on the ability of geomorphic processes to transfer sediments along the paths (i.e. the edges).

**4 Applications to real sediment cascade**

The IC index is now applied to a real sediment cascade, which functioning has been already conceptualized and quantified (Cossart and Fort, 2008; Cossart, 2016). Celse-Nière catchment is located in the french southern Alps, on the eastern flank of the massif des Ecrins. We focus here on the headwater (about 10 km², from 2500 m.asl to 3850 m.asl), still occupied by glaciers. Special attention was already given to the linkages between the glacial margins and the glacio-fluvial systems. The presence of morainic ridges still interrupts the sedimentary cascade system, thus forcing local aggradation and change in the

Nombre : 1 Auteur : reviewer Sujet : HervorhebenDate : 06/12/2016 22:09:02
write "B" in subscript to better indicate that it is F for node B
(FD, FE, FF in line 2f, and throughout the following paragraph)

Nombre : 2 Auteur : reviewer Sujet : Eingefügter Text Date : 06/12/2016 22:04:23
whose / the influence of which

Nombre : 3 Auteur : reviewer Sujet : HervorhebenDate : 06/12/2016 22:07:30
can you really say if an increase by 0.03 is significant ? An increase of 0.02 (from 0.05 to 0.07) was not called significant...
I think such a statement can only be made if a more thorough sensitivity analysis is conducted.

Nombre : 4 Auteur : reviewer Sujet : Eingefügter Text Date : 06/12/2016 22:04:38
whose / the influence of which

Nombre : 5 Auteur : reviewer Sujet : Eingefügter Text Date : 06/12/2016 22:09:53
s

Nombre : 6 Auteur : reviewer Sujet : HervorhebenDate : 06/12/2016 22:10:46
Does that mean that Ai decreases (meaning higher accessibility !?) or that accessibility decreases (which would be signified by increasing Ai !?) ?

Nombre : 7 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 22:17:48
but that's almost trivial considering that the topological distance between A and F is shorter (by one) than that between B and F...

Nombre : 8 Auteur : reviewer Sujet : Eingefügter Text Date : 06/12/2016 22:18:08
s

Nombre : 9 Auteur : reviewer Sujet : HervorhebenDate : 06/12/2016 22:25:11
why does a node property (great centrality) minimise a distance ?
The distance may control this property, not the other way round, right ?
Consider rephrasing please.

Nombre : 10 Auteur : reviewer Sujet : Eingefügter Text Date : 06/12/2016 22:23:50
that are (?)

Nombre : 11 Auteur : reviewer Sujet : HervorhebenDate : 06/12/2016 22:26:16
this is only for the didactic example, right ? In nature, the distance would not increase (roughness/impedance could, increase of course)

Nombre : 12 Auteur : reviewer Sujet : Eingefügter Text Date : 06/12/2016 22:26:28
s

Nombre : 13 Auteur : reviewer Sujet : HervorhebenDate : 06/12/2016 22:27:35
see above comments... a node will not make a distance smaller. It has a small or great distance.

Nombre : 14 Auteur : reviewer Sujet : Eingefügter Text Date : 06/12/2016 22:29:18
increases

Nombre : 15 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 22:30:28
here you could discuss the similarity / difference related to Borselli's index, that would justify the detailed description of the latter in chapter 2.

Nombre : 16 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 22:39:17
it could be discussed whether an index reflecting more process-related properties (e.g. by including roughness, traveltimes, slopes or similar edge properties, or sediment availability as a node property) may at least partially adress functional connectivity; especially if it was strongly correlated to SDR (that is seen as a proxy/performance measure of functional connectivity).

Nombre : 17 Auteur : reviewer Sujet : Eingefügter Text Date : 06/12/2016 22:39:36
whose / the functioning of which

Nombre : 18 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 22:41:18
I suggest that you give a short overview of topographic, climatological and lithological properties (a table might be enough).

Nombre : 19 Auteur : reviewer Sujet : Eingefügter Text Date : 06/12/2016 22:39:53
that is

Earth Surf. Dynam. Discuss., doi:10.5194/esurf-2016-55, 2016
Manuscript under review for journal Earth Surf. Dynam.
Published: 8 November 2016


glacio-fluvial pattern (Fig. 5A). Such a complex assemblage makes this area particularly suitable for assessing connectivity and simulate the impacts of new blockages or, conversely, of some reconnections.

#### 4.1 The structure of the network

From the geomorphological map, the graph has been drawn in a GIS software (QGIS): a regular network of nodes has been created (distance between nodes equals 100 meters). Each node is first characterized by the geomorphic unit to which it belongs, and from geomorphic expertise the linkages between the nodes are digitized. From the network QGIS tools, the adjacency matrix has been set (as an edge list matrix) and exported to R software. In the latter software, the matrix has been converted to an origin-to-destination matrix, and the distance matrix automatically created (a topological distance has been considered) thanks to the igraph package. All calculations on matrices have been conducted in R, and the results have been exported to QGIS to be mapped.

First it can be noticed that only 60% of the total paths are connected to the outlet, the others are connected to permanent sinks. By applying the typology established by Fryirs et al. (2007), disconnections are due to barriers (morainic ridges), buffers (roches-moutonnées and glacio-fluvial terraces) and blankets (screes made of large grain-size boulders) (Fig. 5B). Second, the IC index highlights the influence of the trunk valley located between the margin of Glacier-du-Sélé and the confluence with the Coup-de-Sabre proglacial river (Fig.6A). This observation can be interpreted in terms of sensitivity to external factors at the catchment scale. On the one hand, high-connectivity nodes (e.g. along the trunk valley, the Coup-de-Sabre subcatchment) are able to transfer along the cascade a perturbation due to a geomorphic event. A significant input of sediments (due for instance to hydro-meteorological event) in these areas would increase the sediment delivery at the outlet. On the other hand, any perturbations on the non-connected nodes (e.g. on the southern flank of Ailefroide) would have a null influence on the sediment delivery. The IC index also exhibits a hierarchy between the sources. As they are significantly closer to the outlet all the sources located in the Coup-de-Sabre subcathment have a greater influence on sediment delivery than the sources located in the Ailefroide, Sélé or Boeufs-Rouges areas.

Thus, the map of IC index helps to conceptualize the continuum of sediment transfer, and helps in interpreting monitoring measurements at one point in a catchment (not necessarily at the outlet). The examination of nodes connectivity may be required to establish sampling strategies for small-scale measurements of erosion on the field. Furthermore, this first examination highlights that the impacts of external drivers (anthropogenic impact, hydro-meteorological event and more generally climate change) are space dependent: the impacts are higher and efficiently propagated if they affect high-connectivity areas.

#### 4.2 What if…?

The connectivity hierarchy between nodes can be interpreted as the potential influence of the node on sediment delivery, on the global functioning of the cascade. The IC index and more generally tools provided by graph theory allow simulation t

# Page : 10

Nombre : 1 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 22:45:05

the two scenarios are most significant where the system is close to such changes, i.e. where such changes are likely to happen. You could justify your choice of scenarios along these lines.

Nombre : 2 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 22:49:43

the spatial pattern of these nodes is arranged in a way that the distance between nodes is not always 100m (only for cardinal neighbours), for some adjacent nodes the distance is 141 m (diagonal neighbours). Has this been accounted for ? It should, I think, because distance has been shown to be important in the calculation of the IC.

Nombre : 3 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 22:51:50

does this expertise refer to every single instance, based on your field knowledge ? Or does it refer to a more general knowledge (related to landform types rather than specific cases), i.e. the fact that a lateral moraine forms a buffer ? Did you use diagnostic features to identify coupling in each case ?

Nombre : 4 Auteur : reviewer Sujet : Eingefügter Text Date : 06/12/2016 22:49:59

ological

Nombre : 5 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 22:53:08

Here you could investigate the number and size of connected components, i.e. groups of nodes that form a sediment cascade but are disconnected from other cascades.

Nombre : 6 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 23:04:39

(1) check the definition of barriers and buffers. In my opinion barriers refer to longitudinal (i.e. along the channel network) connectivity, while buffers refer to lateral connectivity (by decoupling hillslope-bourne sediment fluxes from the channel network). It might not apply to the specific landforms you name here.

(2) a morainic ridge surely is a buffer to lateral sediment flux. On the other hand, the same morainic ridge can be a source of sediment (it is dissected by fluvial incision and debris flows). How is that dealt with ?
Is there a single node connected both to upslope and downslope landforms ? Is the upslope cascade interrupted on the landform just upslope of the morainic ridge ?

Nombre : 7 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 23:06:00

Fig 5B only clearly shows moraines as buffers (and as sources - at least it could be interpreted from the arrow with "22")

Nombre : 8 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 23:08:56

important literature that also refers to connectivity:
Fryirs, K.A., 2016. River sensitivity. A lost foundation concept in fluvial geomorphology. Earth Surf. Process. Landforms, n/a-n/a.

Nombre : 9 Auteur : reviewer Sujet : Eingefügter Text Date : 06/12/2016 23:09:13

propagate?

Nombre : 10 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 23:11:18

this conclusion is comparatively trivial and is not derived from the IC computation but directly from the graph structure that has been set up by a geomorphologist. The IC is used for ranking connectivity, not for assessing an "on-off"-state...

Nombre : 11 Auteur : reviewer Sujet : Eingefügter Text Date : 06/12/2016 23:11:39

subcatchment

Nombre : 12 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 23:12:30

predicting the downstream transfer and delivery of sediment fluxes measured at one point ?

Nombre : 13 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 23:14:40

which is a hypothesis that you can't prove by computing an index that implements our theoretical understanding of a geomorphic system. Validation of such an index would require the assessment of the reaction to / propagation of change in relation to the index...

Nombre : 14 Auteur : reviewer Sujet : Durchstreichen Date : 06/12/2016 23:15:05

Nombre : 15 Auteur : reviewer Sujet : Eingefügter Text Date : 06/12/2016 23:15:33

Nombre : 16 Auteur : reviewer Sujet : Eingefügter Text Date : 06/12/2016 23:15:56

of scenarios

Earth Surf. Dynam. Discuss., doi:10.5194/esurf-2016-55, 2016
Manuscript under review for journal Earth Surf. Dynam.
Published: 8 November 2016


predict what can be the more impacting events on the cascade. Two algorithms ere here applied in R to simulate the consequences ocal disconnection and a local reconnection.

First has been asked to remove a node create the ore significant drop in terms of connectivity (Fig. 6B). Th simulation can reflect the possible impact of an anthropogenic feature (e.g. a dam) or of a hillslope process (e.g. m created by a landslide mass or a debris flow). The greater impact would occur if the node located at the toe of Glacier du Sélé srupts. It would imply the disconnection from the outlet f ree main subcascades (organized from ilefroide, Sélé and Boeufs-Rouges sources) so that only 26% percent the nodes would remain connected to the outlet. The disruption would be more significant than in the case of a disruption of the node located at the confluence with Coup-de-Sabre proglacial river. In this latter case, many nodes would be indeed disconnected from the outlet, but the three subcascades of Ailefroide, Sélé and Boeufs-Rouges would be less impacted and would be still self-organized. As a consequence, the structure of the sediment cascade would be less modified.

Second, it has been queried to add a new ate the better improve nt of the overall sediment connectivity (Fig. 6C). This simulation can reflect the disruption of a barrier, the removal of a blanket, for instance following a high magnitude geomorphic event. In that case, a link between Guyard subcatchment and the trunk valley would create the highest IC value at the confluence. Such an increase is due to the high mber of nodes that would become connected to the outlet. Furthermore these nodes (especially the sources) are relatively close to the outlet. A reconnection of subcascade in Ailefroide area would have a lesser impact because of its eccentricity. It can be noticed that the reconnection of Guyard subcascade would decrease the influence of Coup-de-Sabre subcascade on the overall network: under this hypothesis reconnection, all the sources of this area are affected by a decrease of IC index. ding to this new structure of the cascade, the hierarchy of sources would be thus modified: the sources of Guyard area would have a greater influence than Coup-de-Sabre sources, which would have a greater influence than Ailefroide, Sélé and Boeufs-Rouges sources.

As a consequence, t C index provides an exploration of the cascade structure and may explain to what extent a small-scale modification (disruption of a node, creation of a linkage) may result in significant scale geomorphic patterns and processes. More generally, index makes possible comparisons. In this study case comparisons have be made between cascades of different sizes, suggesting that IC index is sufficiently robust allow comparisons in both space and time between various catchments.

## 5 Conclusion

This paper seeks at developing an original methodology dedicated to the study of sedimentary cascades under the hypothesis that connectors and paths influence on sediment delivery is space-dependent. The methods rely on graph theory to assess structural connectivity: sediment cascade is described as a network and consequently as graph. Inspired from indices developed in undirected graphs, a potential flow and an accessibility of geomorphic units (i.e. accessibility to both sediment sources and to the outlet) can be measured throughout the sediment cascade. Both indices are combined to estimate a

Nombre : 1 Auteur : reviewer Sujet : Eingefügter Text Date : 06/12/2016 23:16:01
scenarios

Nombre : 2 Auteur : reviewer Sujet : Eingefügter Text Date : 06/12/2016 23:16:13
of

Nombre : 3 Auteur : reviewer Sujet : Durchstreichen Date : 06/12/2016 23:16:24

Nombre : 4 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 23:18:25
(1) why did you remove a node ? Wouldn't it be more meaningful to remove an edge ?
(2) how was the location of this disconnection chosen ? Deliberately or randomly ? I'd suggest to choose a location where such a disconnection is likely
(same applies for the re-connection, lines 12ff)

Nombre : 5 Auteur : reviewer Sujet : Eingefügter Text Date : 06/12/2016 23:16:33
was removed

Nombre : 6 Auteur : reviewer Sujet : Eingefügter Text Date : 06/12/2016 23:16:37
a

Nombre : 7 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 23:19:22
i.e. the formation of a new connected component ?

Nombre : 8 Auteur : reviewer Sujet : HervorhebenDate : 06/12/2016 23:19:01
a node (or better: edge) is disrupted, it does not disrupt

Nombre : 9 Auteur : reviewer Sujet : Eingefügter Text Date : 06/12/2016 23:19:36
fed by (?)

Nombre : 10 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 23:22:52
suggest to add the change effected by the scenario (a decrease from 60% to 26%)

Nombre : 11 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 23:25:40
...well, but the consequences in terms of SDR would remain the same, right ?
So it remains questionable why two different changes in connectivity (as measured by IC) should lead to the same consequences. Conversely, how valuable is an index that would not predict a change in sediment delivery because two different values would be associated with the same delivery ?
This is a conceptual/theoretical issue you need to discuss.

Nombre : 12 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 23:27:02
here, you add a new edge (not a new node), what makes more sense to me. Consider changing your first scenario accordingly.

Nombre : 13 Auteur : reviewer Sujet : Durchstreichen Date : 06/12/2016 23:25:53

Nombre : 14 Auteur : reviewer Sujet : Durchstreichen Date : 06/12/2016 23:26:03

Nombre : 15 Auteur : reviewer Sujet : Eingefügter Text Date : 06/12/2016 23:27:30
large

Nombre : 16 Auteur : reviewer Sujet : Eingefügter Text Date : 06/12/2016 23:29:45
in this scenario

Nombre : 17 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 23:29:29
why ?
This "why" has two aspects:(1) why does the index change (a numerical issue)
(2) is it plausible that connectivity really changes with this scenario (a geomorphological issue)

Nombre : 18 Auteur : reviewer Sujet : Eingefügter Text Date : 06/12/2016 23:30:11
T

Nombre : 19 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 23:30:33
changes of

Nombre : 20 Auteur : reviewer Sujet : Eingefügter Text Date : 06/12/2016 23:30:39
the

Suite des commentaires de la page 11 sur la page suivante

Earth Surf. Dynam. Discuss., doi:10.5194/esurf-2016-55, 2016
Manuscript under review for journal Earth Surf. Dynam.
Published: 8 November 2016


predict what can be the more impacting events on the cascade. Two algorithms were here applied in R to simulate the consequences a local disconnection and a local reconnection.

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Nombre : 21 Auteur : reviewer Sujet : Eingefügter Text Date : 06/12/2016 23:30:52
enables

Nombre : 22 Auteur : reviewer Sujet : Eingefügter Text Date : 06/12/2016 23:31:01
...between (sub-)catchments ?

Nombre : 23 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 23:34:08
do the data really justify the conclusion that the index is robust (i.e. insensitive to minor changes in parameters) ?? And is such robustness required for the index to be used in comparative studies ?
The Borselli index has issues of comparability because it depends on the size of the contributing area - similar scale-dependence could arise for your IC index, because the number of edges is somehow related to the size of the contributing area.
Reconsider and discuss !

Nombre : 24 Auteur : reviewer Sujet : Durchstreichen Date : 06/12/2016 23:34:35

Nombre : 25 Auteur : reviewer Sujet : Eingefügter Text Date : 06/12/2016 23:34:32
the influence of

Earth Surf. Dynam. Discuss., doi:10.5194/esurf-2016-55, 2016
Manuscript under review for journal Earth Surf. Dynam.
Published: 8 November 2016


connectivity index that reveals how influent is a node within a sediment cascade. Specific applications were ~~led~~ [1] a GIS software (QGIS) but also in software dedicated to data analysis and ~~matrices~~ [2] lculations (R).

The application on a virtual and simple catchment, and then on a real catchment, exhibits how geomorphic processes [3] iations may lead (or not) to sediment mobilization and exportation, from upper slopes to the outlet of watersheds. The behaviour of the sediment cascades appears space-dependent: the geometry of paths and the location of nodes have a direct influence on the structural connectivity and then on the ability of the sediment cascade to deliver sediments. It is also highlighted that the impact of an external force on the sediment cascade depends on the location where it acts: the higher the connectivity of the node, the higher the impact on the cascade. Some simulations can moreover be led to predict how local perturbations may have an impact on the overall cascade.

This issue relies on main challenges in geomorphology and may lead to [4] eep applications on river management, especially in Western Europe where rivers are affected by a strong deficit of sediment load. An assessment of connectivity will help at describing coupling patterns, scale dependence of erosional processes, to understand and predict how policies at catchment scale may supply sediments to the river system (dismantlement of hydraulic infrastructures, changes in terms of land use, etc.).

**References**

Ali, G.V. and Roy, A.G.: Revisiting hydrologic sampling strategies for an accurate assessment of hydrologic connectivity in humid temperate systems. Geography Compass 3, 350–374, 2009

Baartman, J.E.M., Masselink, R., Keesstra, S.D. and Temme, A.J.A.M. : Linking landscape morphological complexity and sediment connectivity. Earth Surface Processes and Landforms 38, 1457–1471, 2013.

Belisle, M.: Measuring landscape connectivity: the challenge of behavioural landscape ecology. Ecology 86, 1988–1995, 2005.

Bennett, G. : Integrating biodiversity conservation and sustainable use. Lessons learned from ecological networks. World Conservation Union (IUCN), Gland, Switzerland, 2004.

Brierley, G., Fryirs, K. and Jain, V. : Landscape connectivity: the geographic basis of geomorphic applications. Area 38(2), 165–174, 2006.

Borselli, L., Cassi, P. and Torri, D.: Prolegomena to sediment and flow connectivity in the landscape: a GIS and field numerical assessment. Catena 75, 268-277, 2008.

Bracken, L.J., Turnbull, J., Wainwright, J. and Bogaart, P.: Sediment connectivity: a framework for understanding sediment transfer at multiple scales. Earth Surface Processes and Landforms 40(2), 177-188, 2015.

Bravard, J.P.: Le temps et l'espace dans les systèmes fluviaux, deux dimensions spécifiques de l'approche géomorphologique. Annales de Géographie 107(599), 3-15, 1998.

# Page : 12

| | | | |
|---|---|---|---|
| Nombre : 1 | Auteur : reviewer | Sujet : Eingefügter Text | Date : 06/12/2016 23:40:23 |

implemented

| | | | |
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x

| | | |
|---|---|---|
| Nombre : 3 | Auteur : reviewer | Sujet : HervorhebenDate : 06/12/2016 23:40:51 |

terminology

| | | |
|---|---|---|
| Nombre : 4 | Auteur : reviewer | Sujet : HervorhebenDate : 06/12/2016 23:41:24 |

??

Cavalli, M., Trevisani, S., Comiti, F. and Marchi, L.: Geomorphometric assessment of spatial sediment connectivity in small Alpine catchments. Geomorphology 188, 31-41, 2013.

Chorley, R.J. and Kennedy, B.A. Physical Geography: A Systems Approach. Prentice-Hall International, London, 370 pp, 1971.

Cole, J.P. and, King C.A.M. : Quantitative Geography: Techniques and theories in geography, Wiley, New York, 471 pp, 1968.

Cossart, É: La recrudescence de l'activité torrentielle dans un bassin versant en cours de déglaciation au cours du XXe siècle. Géomorphologie : relief, processus, environnement 3, 225-240, 2004.

Cossart, É. and Fort, M.: Sediment release and storage in early deglaciated areas: Towards an application of the exhaustion model from the case of Massif des Écrins French Alps since the Little Ice Age. Norsk Geografisk Tidsskrift – Norwegian Journal of Geography 62, 115-131, 2008.

Cossart, É.: L'(in)efficacité géomorphologique des cascades sédimentaires en question : les apports d'une analyse réseau. Cybergeo : European Journal of Geography 778, DOI : 10.4000/cybergeo.27625, 2016.

Delahaye, D., Guermond, Y. and Langlois, P.. Spatial interaction in the run-off process. Cybergeo : European Journal of Geography 213, DOI : 10.4000/cybergeo.3795, 2001.

Douvinet, J., Delahaye, D. and Langlois, P. : Modélisation de la dynamique potentielle d'un bassin versant et mesure de son efficacité structurelle. Cybergeo: European Journal of Geography 412, DOI : 10.4000/cybergeo.16103, 2008.

Faulkner, H.: Connectivity as a crucial determinant of badland geomorphology and evolution. Geomorphology 100(1-2), 91-103, 2008.

Ferguson, R.I.: Channel forms and channel changes. In: Lewin, J. (Ed.) British Rivers. Allen and Unwin, London. pp. 90-125, 1981.

Freeman, L.C.: Centrality in social networks conceptual clarification. Social networks 1(3), 215–239, 1979.

Fryirs, K.: DisConnectivity in catchment sediment cascades: a fresh look at the sediment delivery problem. Earth Surface Processes and Landforms Landforms 38, 30–46, 2013.

Fryirs, K., Brierley, G.J., Preston, N.J. and Kasai, M.. The disconnectivity of catchment-scale sediment cascades. Catena, 70, 49-67, 2007.

Gleyze, J.F.. Effets spatiaux et effets réseau dans l'évaluation d'indicateurs sur les nœuds d'un réseau d'infrastructure. Cybergeo: European Journal of Geography 370, DOI : 10.4000/cybergeo.5532, 2008.

Gumiere, S.J., Le Bissonnais, Y., Raclot, D. and Cheviron, B.: Vegetated filter effects on sedimentological connectivity of agricultural catchments in erosion modelling: a review. Earth Surface Processes and Landforms 36, 3–19, 2011.

Haggett, P. and Chorley, R.J.: Network analysis in geography, Edward Arnold, Science, 348 pp, 1969.

Harvey, A.M.: Coupling between hillslopes and channels in upland fluvial systems: implications for landscape sensitivity, illustrated from the Howgill Fells, northwest England. Catena 42, 225-250, 2001.

Heckmann, T. and Schwanghart, W.: Geomorphic coupling and sediment connectivity in an alpine catchment - exploring sediment cascades using graph theory. Geomorphology 182, 89-103, 2013.

Heckmann, T., Schwanghart, W. and Phillips, J.D.: Graph theory: Recent developments of its application in geomorphology. Geomorphology 243, 130-146, 2015.

Kimberly, A.W., Gardner, R.H. and Turner, M.G.: Landscape connectivity and population distributions in heterogeneous environments. Oikos 78, 151–169, 1997.

Ludwig, J.A., Eager, R.W., Bastin, G.N., Chewings, V.H. and Liedloff, A.C.: A leakiness index for assessing landscape function using remote sensing. Landscape Ecology 17, 157–171, 2002.

McGuinness, J.L., Harrold, L.L. and Edwards, W.M.: Relation of rainfall energy streamflow to sediment yield from small and large watersheds. Journal of Soil and Water Conservation 26, 233-235, 1971.

Newman, M.E.J.: Networks: An Introduction, Oxford University Press, 2010.

Pumain, D. and Saint-Julien T.: Analyse spatiale : les localisations, Cursus, Armand Colin, Paris, 192 pp, 2010.

Renard, K., Foster, G.R., Weessies, G.A., Mc Cool, D.K. and Yodler, D..C. Predicting soil erosion by water: a guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). U.S. Department of Agriculture. Agriculture Handbook 703, 1-384, 1997.

Schumm, S., 2005. River variability and complexity, Cambridge University Press, 219 p, 2005.

Tischendorf, L and and Fahrig, L.: How should we measure landscape connectivity? Landscape Ecology 15, 633–641, 2000.

Turnbull, L., Wainwright, J., Brazier, R.E.: A conceptual framework for understanding semi-arid land degradation: ecohydrological interactions across multiple-space and time scales. Ecohydrology 1, 23–34, 2008.

Uezu, A., Metzger, J.P. and Vielliard, J.M.E.: Effects of structural and functional connectivity and patch size on the abundance of seven Atlantic forest bird species. Biological Conservation 123, 507–519, 2005.

Viel V.: Analyse spatiale et temporelle des transferts sédimentaires dans les hydrosystèmes normands. Exemple du bassin versant de la Seulles. Ph-D Thesis, Université de Caen, 382 pp, 2012.

Wainwright, J., Turnbull, L., Ibrahim, T.G., Lexartza-Artza, I., Thornton, S.F. and Brazier, R.E.: Linking environmental regimes, space and time: interpretations of structural and functional connectivity. Geomorphology, 126: 387–404, 2011.

Walker, R.G.: Perspective, facies modelling and sequence stratigraphy. Journal of Sedimentary Petrology 60, 777-786, 1990.

Walling, D.E.: The sediment delivery problem. Hydrology, 69, 209-237, 1983.

Wischmeier, W.H. and Smith, D.D.: Predicting Rainfall Erosion Losses - A Guide to Conservation Planning. U.S. Department of Agriculture. Agriculture Handbook 537, 1-58, 1978.

With, K.A., Gardner, R.H. and Turner, M.G.: Landscape connectivity and population distributions in heterogeneous environments. Oikos 78, 151–169, 1997.

| | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| A | 1 | 0 | 0 | 1 | 0 | 0 | 0 |
| B | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| C | 0 | 0 | 1 | 1 | 0 | 0 | 0 |
| D | 0 | 0 | 0 | 1 | 1 | 0 | 0 |
| E | 0 | 0 | 0 | 0 | 1 | 1 | 0 |
| F | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| G | 0 | 0 | 0 | 0 | 1 | 0 | 1 |

**Table 1: Adjacency matrix of the virtual sediment cascade**

| | **0** | **1** | **2** | **3** | **4** | **5** | $F^{i}_{jo}$ | **Fi** |
|---|---|---|---|---|---|---|---|---|
| **A** | **1** | **0** | **0** | **0** | **0** | **0** | **1** | **0,05** |
| **B** | **1** | **0** | **0** | **0** | **0** | **0** | **1** | **0,05** |
| **C** | **1** | **1** | **0** | **0** | **0** | **0** | **2** | **0,09** |
| **D** | **1** | **2** | **1** | **0** | **0** | **0** | **4** | **0,18** |
| **E** | **1** | **2** | **2** | **1** | **0** | **0** | **6** | **0,27** |
| **F** | **1** | **1** | **2** | **2** | **1** | **0** | **7** | **0,32** |
| **G** | **1** | **0** | **0** | **0** | **0** | **0** | **1** | **0,05** |
| | | | | | | **Total** | **22** | |

**Table 2: Analysis of the potential sediment flow within the sediment cascade. The first rows correspond to the iterations simulating the evacuation of sediments. At the right, the rows detail the calculation of the Flow index.**

Earth Surf. Dynam. Discuss., doi:10.5194/esurf-2016-55, 2016
Manuscript under review for journal Earth Surf. Dynam.
Published: 8 November 2016


| | A | B | C | D | E | F | G | $D_{i,}$ | Ai |
|---|---|---|---|---|---|---|---|---|---|
| **A** | **0** | **0** | **0** | **1** | **2** | **3** | **0** | **6** | **0,17** |
| **B** | **0** | **0** | **1** | **3** | **4** | **5** | **0** | **13** | **0,37** |
| **C** | **0** | **0** | **0** | **2** | **3** | **4** | **0** | **9** | **0,29** |
| **D** | **0** | **0** | **0** | **0** | **1** | **2** | **0** | **3** | **0,26** |
| **E** | **0** | **0** | **0** | **0** | **0** | **1** | **0** | **1** | **0,34** |
| **F** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0,49** |
| **G** | **0** | **0** | **0** | **0** | **1** | **2** | **0** | **3** | **0,09** |
| $D_{.i}$ | **0** | **0** | **1** | **6** | **11** | **17** | **0** | **35** | |

**Table 3: Distance matrix (origin-to-destination) of the virtual sediment cascade. At the right, the rows detail the calculation of the accessibility index.**

| | 0 | 1 | 2 | 3 | 4 | 5 | $F^{i}_{jo}$ | Fi | Ai | ICi |
|---|---|---|---|---|---|---|---|---|---|---|
| **A** | **1** | **0** | **0** | **0** | **0** | **0** | **1** | **0,03** | **0,18** | **0,20** |
| **B** | **2** | **0** | **0** | **0** | **0** | **0** | **2** | **0,07** | **0,35** | **0,20** |
| **C** | **1** | **2** | **0** | **0** | **0** | **0** | **3** | **0,10** | **0,28** | **0,38** |
| **D** | **1** | **2** | **3** | **0** | **0** | **0** | **6** | **0,21** | **0,25** | **0,83** |
| **E** | **1** | **2** | **2** | **3** | **0** | **0** | **8** | **0,28** | **0,33** | **0,85** |
| **F** | **1** | **1** | **2** | **2** | **3** | **0** | **9** | **0,31** | **0,55** | **0,56** |
| **G** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0,00** | **0,08** | **0,00** |
| | | | | | | **Total** | **29** | | | |

**Table 4: Analysis of the potential flow and calculation of connectivity following a new parameterization. The rows indicate the patterns of sediment evacatuation at each iteration of the simulation. Source B provides twice more sediments and the distance between E and F is twice than during the initial conditions.**

Earth Surf. Dynam. Discuss., doi:10.5194/esurf-2016-55, 2016
Manuscript under review for journal Earth Surf. Dynam.
Published: 8 November 2016


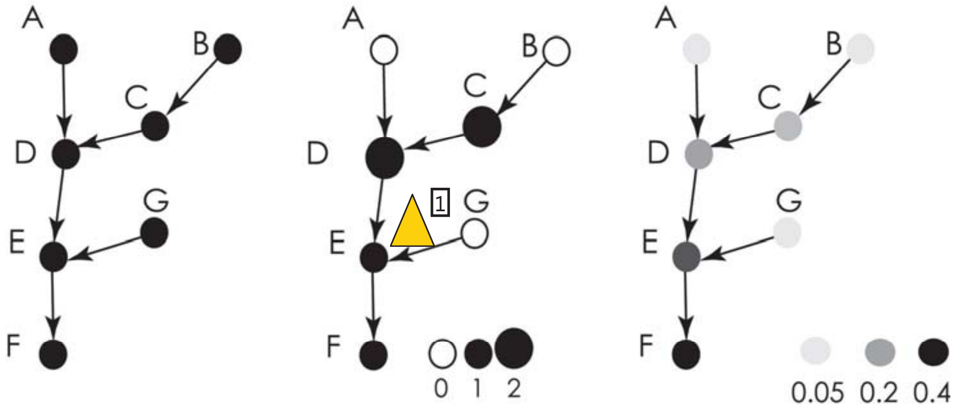


**Figure 1: The virtual sediment cascade. A: The structure of the cascade, represented by a graph. B: Potential flow of sediments after one iteration during the simulation. C: Map of flow index values.**

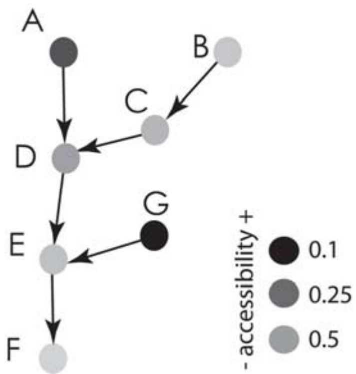


**Figure 2: Assessment of accessibility index within the virtual sediment cascade.**

Nombre : 1 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 23:44:57

if all the nodes contain and pass on sediments, A=B=G=0, D=E=2, and C=F=1 (which is consistent with table 2
In Fig1B, C and E have the wrong amount of sediment after 1 iteration.
Could it be that the "flow index" (not named in the text) in 1C is wrong as well ? Please double-check, in all Figures and tables.

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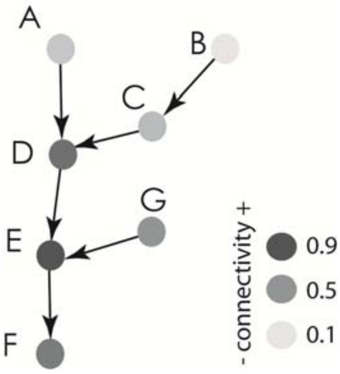


**Figure 3: Assessment of connectivity index within the virtual sediment cascade.**

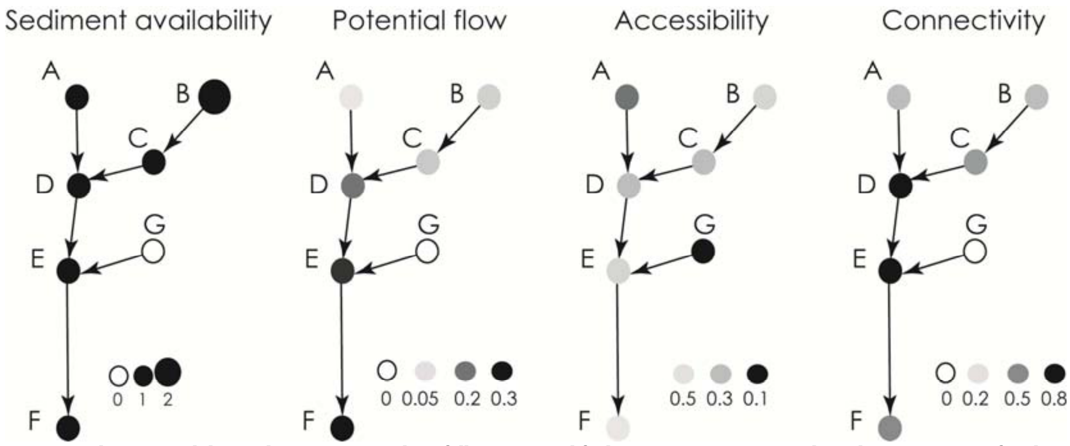


**Figure 4: Flow, accessibility and connectivity indices following a modified parameterization. Note how the connectivity of node D is reinforced, and connectivity of F gets lower.**

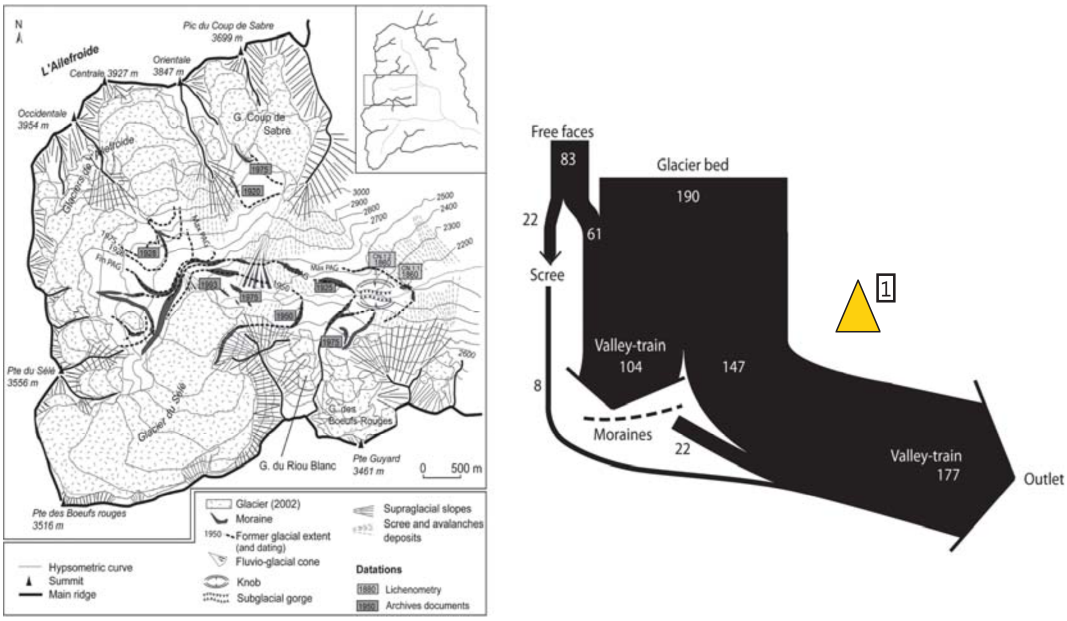


**Figure 5: Celse-Nière catchment and sediment cascade. A: Geomorphological map of the study area. Note the various morainic ridges that disconnect the sediment cascade. B: Synthetic pattern of the potential flow within the sediment cascade.**

# Page : 19

Nombre : 1 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 23:06:21

(1) Missing units
(2) The numbers in 5B are not addressed (not even mentioned) in the text.
A few lines in the text on the geomorphological map 5A (and its main features) could also help.

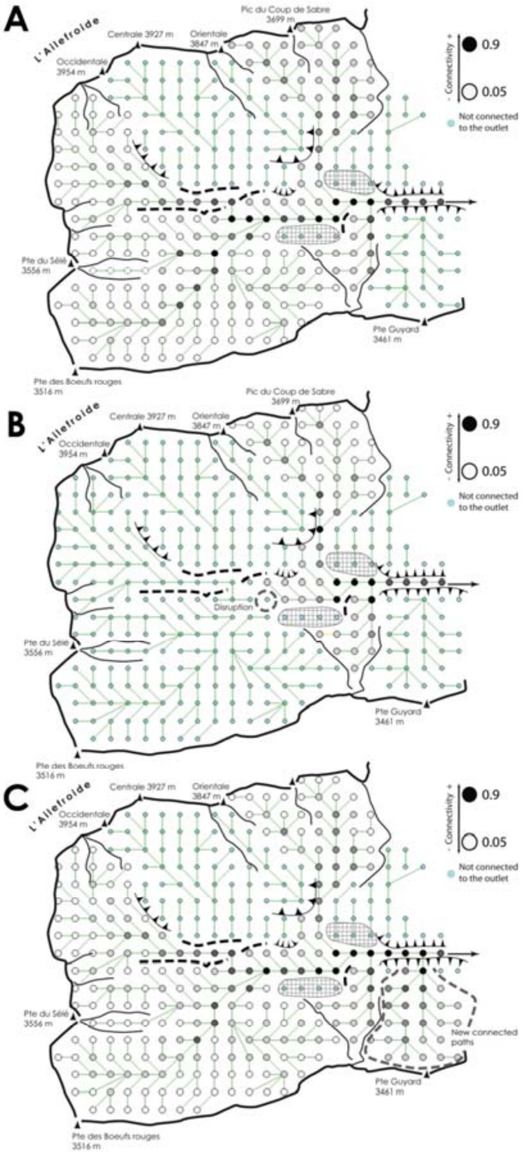


**Figure 6: Assessment of connectivity. A: Current structure of the cascade. B: Connectivity map after the simulation of a disruption at Sélé toe. C: Connectivity map after the simulation of a reconnection at Guyard outlet.**

# Page : 20

Nombre : 1 Auteur : reviewer Sujet : Notiz Date : 06/12/2016 23:47:36

scale bar is missing

different length of diagonal vs. cardinal linkages presumably not accounted for => needs to be addressed

Consider evaluating the number and size of decoupled "connected components", i.e. those subcascades that are not connected to the outlet (not graphically, but in the text)