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Modeling of connectivity: What for? How do we do it? Where to go?

Frédéric Darboux

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Modeling of connectivity: What for?

How do we do it? Where to go?



Foreword

- Surface hydrology and sediment transport
- Not a review
- A few insights about how numerical models are used for connectivity

Questions addressed using models

- Where are the links/connections in the watershed?
- Are they active/How long do they last?
- How do they behave *as a whole*?

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How close to reality?

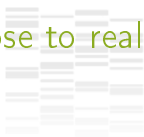
Hydraulic models vs. Phenomenologic models

- Distance to reality
- Input parameters
- Computation time
- Result interpretation
- Skills

Which one is better?

Hydraulic models are better for
phenomenologic models are better for

How close to reality?



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Which one is better?

Hydraulic models: [Hydroinformatics 2018, 19th Water Technology Conference, 2018, 19th International Conference on Urban Storm Drainage, 2018](#)

Phenomenologic models: [Hydroinformatics 2018, 19th Water Technology Conference, 2018, 19th International Conference on Urban Storm Drainage, 2018](#)

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According to Antoine *et al.* (2009, Adv. Water Res.):

Simple can be good enough.

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Spatial distribution



Some kind of spatial distribution must be included

⇒ spatially-distributed models (1D, 2D, 3D)

2 (related) challenges

Algorithms make a difference

Details are critical

Spatial distribution



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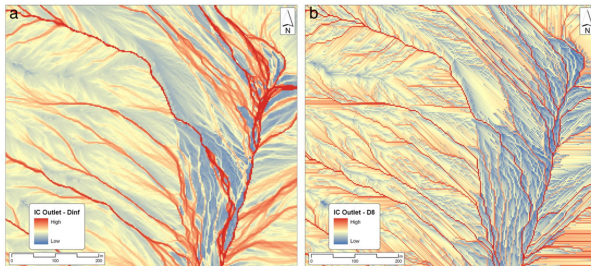
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Examples on flow accumulation algorithms



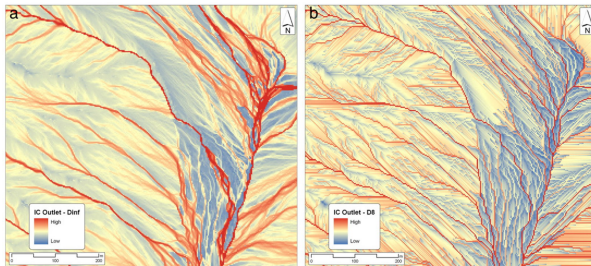
[Cavalli *et al.*, 2013, *Geomorphology*]

How sensitive to data resolution?

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Algorithms make a difference

Examples on flow accumulation algorithms

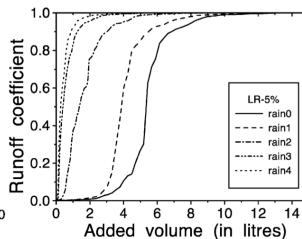
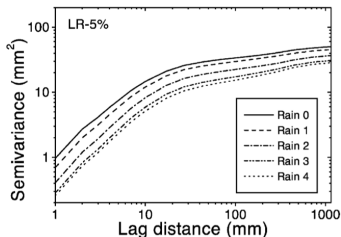


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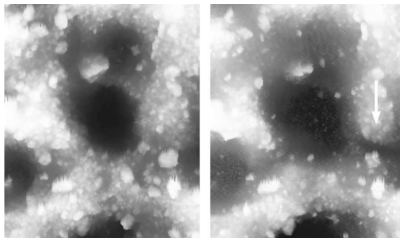


[Darboux et al., 2001, Catena]

⇒ Can we account for details
without representing them explicitly?

2 (related) challenges

Details are critical

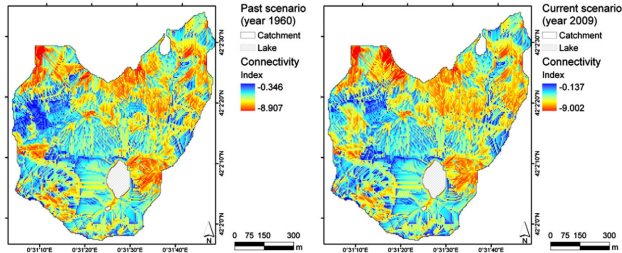


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From pattern to connectivity

Spatial data + spatial model \implies spatial pattern

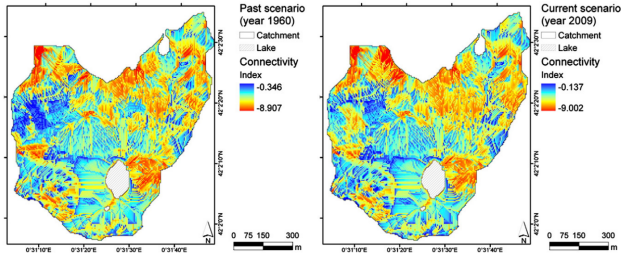


[López-Vicente *et al.*, 2013, Catena]

How to go from a (detailed) connection map to an (overall) connectivity value?

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Indices!



Distributed models: tools to find overall connectivity indices

An overall connectivity index = a lumped parameter!

⇒ From spatially distributed models to non-spatially distributed models.

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...but which one?

Connectivity indicator	Connectivity type	Information requirement	discriminant?
(1) Semivariogram	Structural	Sampling points	No
(2) Relative bivariate entropy	Structural	Sampling points	No
(3) <i>n</i> -Point rectilinear connectivity	Structural	Transect information	No
(4) Connectivity function integral scale	Structural	Full knowledge	Yes
(5) Euler number	Structural	Full knowledge	Yes
(6) Percolation thresholds	Structural	Full knowledge	Yes
(7) Relative surface connection function	Functional	Full knowledge	Yes

[Antoine *et al.*, 2009, *Adv. Water Res.*]

RSC: The connectivity indicator for overland flow?

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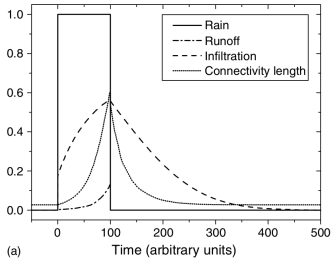
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RSC: The connectivity indicator for overland flow?

+1D: time!



Connectivity changes with time



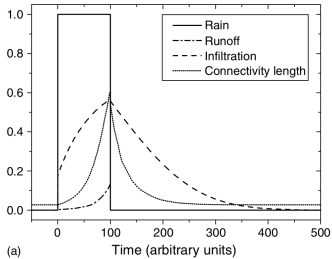
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Connectivity to the outlet \neq Connectivity inside the system

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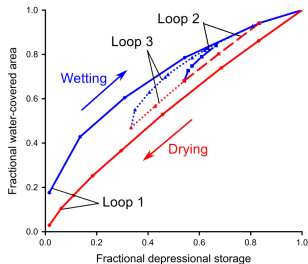


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How to deal with the temporal pattern?



[Shook *et al.*, 2011, *Hydro. Proc.*]

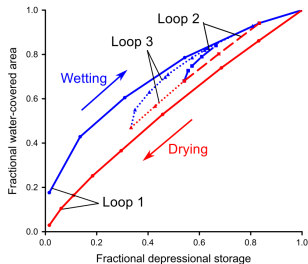
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Hysteresis \implies Non-linear (i.e. non proportional) behavior

\implies A very rich dynamics, *but under-studied.*

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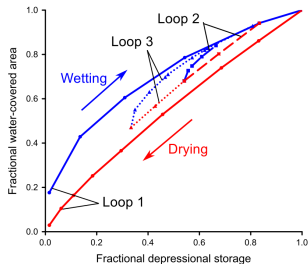
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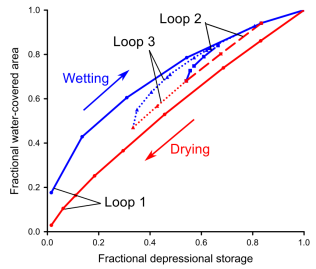
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Poor sediments...

Few works on modelling sediment connectivity

- López-Vicente *et al.*, 2013, Catena
- Cavalli *et al.*, 2013, Geomorphology

Water connectivity vs Sediment connectivity

In hydrology, you need water to carry the sediments

- Sediment connection \Rightarrow Water connection
- Water connection \nRightarrow Sediment connection

More work on sediment connectivity needed,
and models can help on this.

Connectivity-related theories: Inputs & Outputs

Theoretical inputs

Percolation theory



- [Darboux *et al.*, 2002, *Earth Surf. Proc. Landf.*]
- [Lehmann *et al.*, 2007, *Hydrol. Earth Syst. Sci.*]
- [Harel *et al.*, 2013, *Water Res. Research*]

Graph theory



- [Heckmann *et al.*, 2013, *Geomorphology*]

Queuing theory



- [Harel *et al.*, 2013, *Water Res. Research*]

Theory: Inputs & Outputs



Theoretical outputs

- Simplification in modeling
- Understanding
- Scale change

Questions that could be addressed

- Do connection directions matter? How much?
- How to account for connection intensity?

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Do we need data?



Measured data

Study of one watershed:

- What are the important features?
- How to make things more general?
- How to go farther than case studies?

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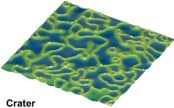
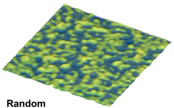
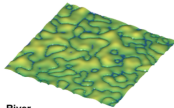
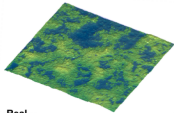
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Computer-generated data



[Peñuela *et al.*, 2013, *Hydrol. Earth Syst. Sci.*]

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generate your data!

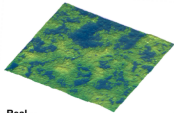
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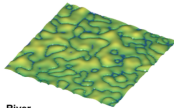
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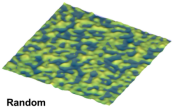
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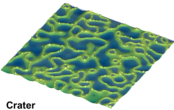
Real



River



Random



Crater

[Peñuela *et al.*, 2013, *Hydrol. Earth Syst. Sci.*]

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Conclusions



- Connectivity is about space and time patterns.
- Justify that accounting for connectivity is valuable (and not just state it).
- Justify your algorithms.
- How to account for details.
- Combining numerical modeling and theory application.
- From case study to proven understanding (using data generation).
- From spatially-distributed modeling to a lumped index (ultimate goal).