Physical similarity vs Hydrological similarity

Do we talk about the same concept?

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Looking at Catchments in Colors, 10-12 November 2010, Luxembourg,
Physical and behavioural similarity

Will they react similarly to a stimulus?

Can the answer of one of them be considered as a good approximation of the other?

Several studies* have shown that:
- monozygotic twins behave much more similarly than dizygotic twins
- monozygotic twins raised apart from each other tend to behave more like each other than other people

(*e.g. Segal et al., 2008, Segal, 2010)
Phenotype vs Genotype: a problem of logic

• ‘True’ (monozygotic) twins share the same genotype. This implies that:
  – if raised in a similar environment, they will behave in a similar fashion
  – they look physically like each other

• However, the reciprocal is not necessarily true. The fact that two individuals look (more or less) alike:
  – does not ensure that they share the same genotype
  – does not ensure that they will behave similarly
What about catchments?

- Catchments are never twins (not even paired catchments!)
- … but may be cousins!
- They may show some degree of physical similarity (to be defined on the basis of a selection of physical descriptors)
- Does this physical similarity implies a similarity of hydrological responses?

… a tricky question for the application of hydrological models on ungauged basins

Twin Streams catchment, New Zealand (Reid et al., Univ. Auckland, NZ)
Common regionalization procedure of hydrological models

Parameter sets on gauged donor catchments

Ungauged target catchment (receiver)

Transfer of parameter set based on physical similarity

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Assumptions underlying parameter transfer

• **Assumption #1:**
  Similarity of model parameters sets means similarity of catchment hydrological behavior

  ✓ If we accept the very principle of a model, we have to accept this assumption: the parameter set is the genotype of the catchment

  ✓ Problem: calibrated parameter values are influenced by
    – Interactions between parameters
    – Possible biases/errors in calibration data
    – Possibly sub-catchment variability

• **Assumption #2:**
  Physical similarity of two catchments implies their hydrological similarity

  ✓ Problem: Difficulty to identify the truly relevant physical characteristics - what counts is often unobservable and/or non quantifiable
Study objective and method

- Determine the extent to which readily available catchment properties explain catchment hydrological behavior

- Approach:
  1. Use a large set of $N$ gauged catchments
  2. For each catchment, determine:
     - the $n$ most hydrologically similar catchments
     - the $n$ most physically similar catchments
  3. Test whether the two subsets significantly overlap
Definition of hydrological similarity

- Based on performance in simulating flows on the target catchment

\[ \text{Target catchment A} \quad \{\theta\}_A, P_A, Q_A \]
\[ \text{Eff(\{\theta\}_A, P_A, Q_A)} \]

\[ \text{Donor catchment B} \quad \{\theta\}_B \]
\[ \text{Eff(\{\theta\}_B, P_A, Q_A)} \]

\[ \text{Eff(\{\theta\}_B) \geq 0.9 \times \text{Eff(\{\theta\}_A)}} \]

- Yes: B similar to A
- No: B not similar to A

- Repeat the test for the \( N-1 \) donor catchments of the dataset to determine the \( n \) hydrologically similar catchments
  (Note: \( n \) depends on the target catchment considered)
Definition of physical similarity

- Physical similarity is based on Euclidian distance in the normalized catchment property space

\[ \text{dist}_{A,B} = \sqrt{\sum_{j=1}^{J} w_j \left( \frac{X_{A,j} - X_{B,j}}{\sigma_{X,j}} \right)^2} \]

where
- \( J \) : total number of phys. descriptors
- \( X_{A,j}, X_{B,j} \) : values of descriptor \( j \) on A and B
- \( \sigma_{X,j} \) : st. dev. of descriptor \( j \)
- \( w_j \) : weight of descriptor \( j \)

- We consider a ‘blend’ of physical descriptors : weights are either set equal or optimized

- Allows identifying the \( n \) catchments most physically similar to target catchment A
Significance of overlap

- Count the number \( m \) of catchments that are both hydrological and physical cousins.
- Determine the probability of this overlap to have occurred by chance:

\[
H_0: \text{there is no difference in the overlaps obtained by random sampling and by the physical similarity approach.}
\]

- Type I error: degree to which the two sets of cousins significantly match.

- Probability of obtaining at least \( m \) catchments given \( N \) and \( n \):

\[
P(X \geq m) = \sum_{k=m,n} \binom{n}{k} \binom{N-n}{n-k} \frac{N}{n}
\]

- The lower the \( P \)-value, the less likely the pool of catchments was selected randomly.
- 10% significance level considered.
Data set

- 893 French catchments
- Daily time series of P, PE and Q over 1995-2005
- 7 catchment descriptors
  - Catchment area
  - Aridity index
  - Catchment slope
  - Drainage density
  - Median altitude
  - Fraction of forest cover
  - BFI
Models

- 2 lumped hydrological models GR4J and TOPMO (4 and 6 free parameters)
- Calibration using NSE(sqrt(Q))
Results
Is hydrological similarity model-dependent?

- Larger number of hydrologically similar catchments for GR4J on average (probably due to the lower number of parameters)

- Number of hydrologically similar catchments tends to increase with calibration performance

- For 80% of the target catchments, similar pools of hydrologically similar catchments for the two models

- For 10% of the target catchments, no overlap (often due to the absence of hydrologically similar catchments for at least one model)
Can we make physical and hydrological similarity match each other?

Nine combinations of descriptors tested:
- Each descriptors taken individually
- Naïve blending (equal weight)
- Optimised weighting

- Four descriptors more informative (slope, aridity, drainage density, forest cover)
- Blending much better than using individual descriptors
- Optimised weighting not much better than naïve blending
- Significant overlap for more than 60% of catchments (P < 0.1) but null for 17%
Conclusions and perspectives

- Physical and hydrological similarities measures are in agreement for only 60% of the target catchments
- Almost impossible to find overlap between physically and hydrologically similar catchments in 15% of cases
- Catchments for which the overlap is low are characterized by atypical long-term water balance and unresponsiveness

- Need for searching for new more relevant descriptors
- Possible use for regionalized functional characteristics to constrain model parameterization

For more details:
Thank you