What is a ‘good’ hydrological model ?

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With contributions of

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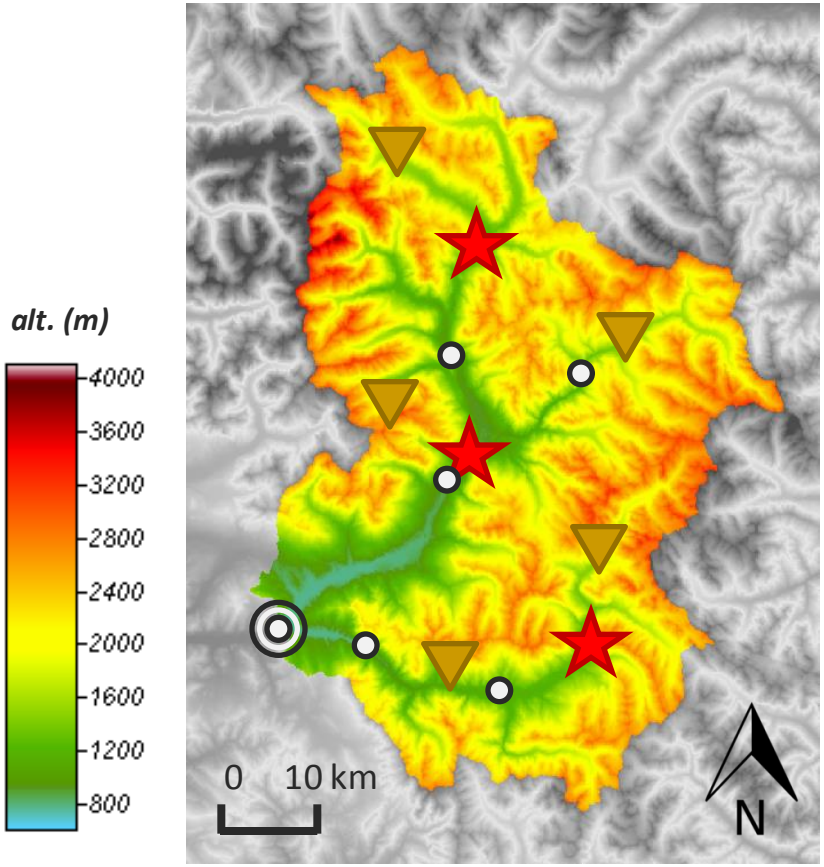
Why asking this question?

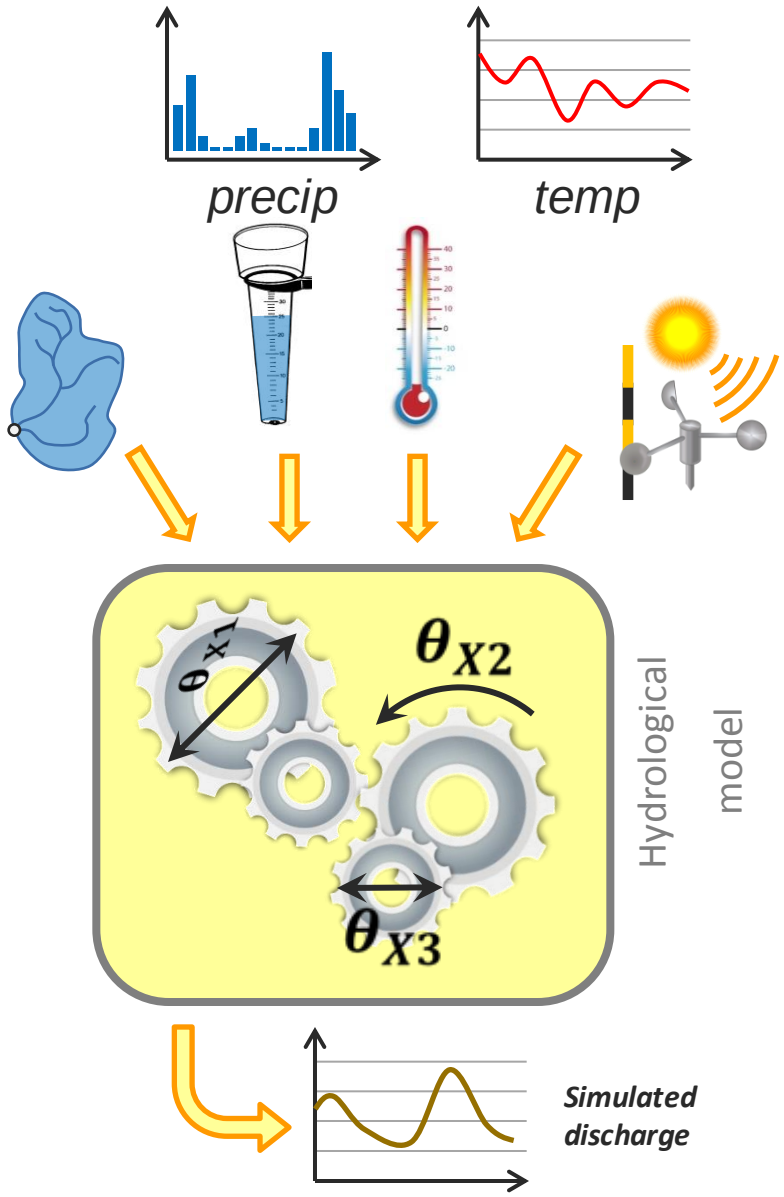
- **We need models for climate change studies**
- **We use them for testing scientific hypotheses**
- **We use them as decision support tools**

What hydrological models look like

catchment



Q_{obs} T_{obs} P_{obs} ...



Other hydrological models…

Static models

$$Q = aP + b$$

$$Q = aP^b$$

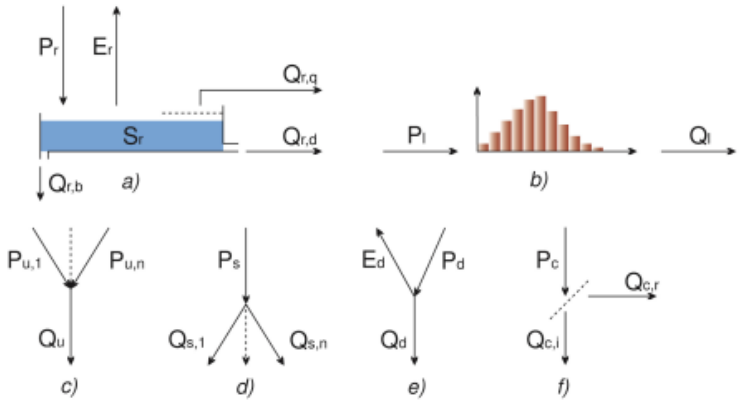
$$Q = aP^b E_0^c$$

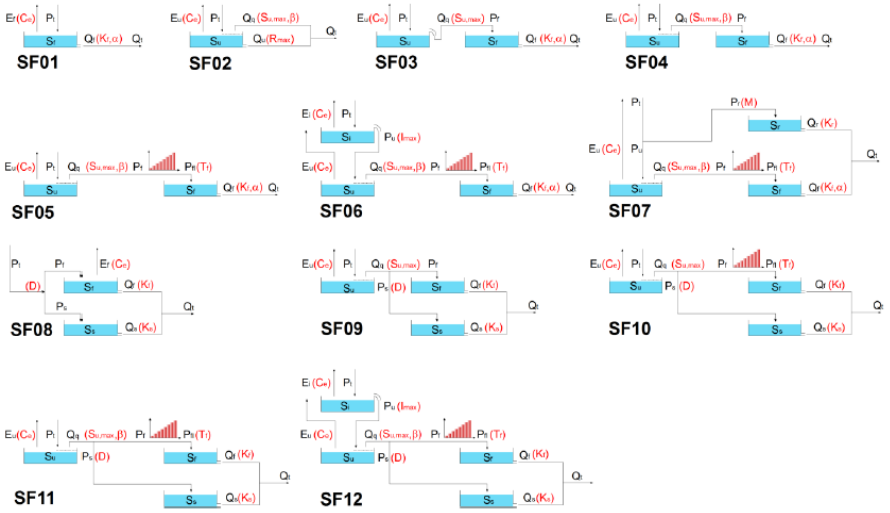
$$Q = aP + bE_0 + c$$

$$\frac{Q}{P} = 1 - \frac{1}{\left(1 + \left(\frac{P}{E_0}\right)^n\right)^{\frac{1}{n}}}$$

etc…

Dynamic models





Elementary building blocks for dynamic rainfall-runoff models

Why asking this question?

- **No hydrological model has achieved global supremacy over the others**
- **The number of models produced by hydrologists keeps rising**

‘*one hydrologist ≈ one model*’

- **Producing one’s own model is certainly considered as a way to demonstrate scientific status and independence…**

Why asking this question?

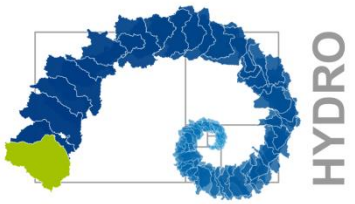
- **We have to get used to live in a world of large model diversity…**

Why asking this question?

- **We have to get used to live in a world of large model diversity…**
- **… but need to be able to recognize their essential properties, qualities and drawbacks, the basic principles on which they are built**
  - ***Which hypothesis can we test with which model?***
  - ***Which decision can we base on which model?***

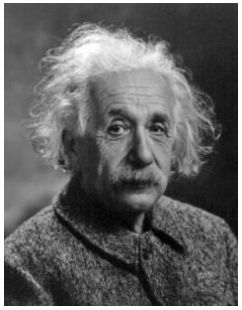
What did famous scientists say on this topic?

(a personal selection)



A few citations…

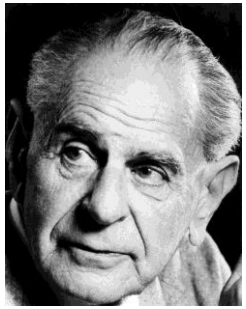
- **« Make your model as simple as possible, but no simpler »**
  - ➲ Albert Einstein (1879-1955)



- ***The level of complexity of a model should be kept as low as possible***
- ***At equal performance, prefer the simplest model***
- ***There is however a limit below which a model will not be useful any more***

A few citations…

- **« A model can be falsified [refuted] but never validated »**
  - ➲ Karl Popper (1902-1994)



- ***A model cannot be proven true: at most we can say that it corroborates observed facts***
- ***A model can and should be challenged by decisive experiments***
- ***If is good practice to keep the model as testable as possible***

A few citations…

- **« All models are wrong, some are useful »**
  - Georges Box (1919-2013)

- ***A model is not meant to be true and represent perfectly the reality, but to serve a given purpose***
- ***A model is neither good nor bad:***
  - *a model is just adapted (or not) to the use we have in mind*
  - *efficient (or not) in simulating the real system we want to reproduce*

What famous hydrologists have written

- **Klemeš (1986): no validation, eventually an 'operational adequation'**
  - Klemeš, V.: Operational testing of hydrologic simulation models, Hydrological Sciences Journal, 31, 13-24, 1986.
- **Konikow & Bredehoeft (1992): models cannot be validated**
  - Konikow, L. F., and Bredehoeft, J. D.: Ground-water models cannot be validated, Advances in Water Resources, 15, 75-83, 1992.
- **de Marsily et al. (1992): validation is not the point: hydrologists do not aim for certainty and perfection… they just do the best they can**
  - de Marsily, G., Combes, P., and Goblet, P.: Comment on 'Ground-water models cannot be validated', by L.F. Konikow and J.D. Bredehoeft, Advances in Water Resources, 15, 367-369, 1992.
- **Oreskes et al. (1994): models can only be evaluated in relative terms**
  - Oreskes, N., Shrader-Frechette, K., and Belitz, K.: Verification, validation, and confirmation of numerical models in the earth sciences, Science, 263, 641-646, 1994.

- ***A discussion of these papers is available in:***
  - Refsgaard, J. C., and Knudsen, J.: Operational validation and intercomparison of different types of hydrological models, Water Resour. Res., 32, 2189-2202, 1996.
  - Andréassian, V., Perrin, C., Berthet, L., Le Moine, N., Lerat, J., Loumagne, C., Oudin, L., Mathevet, T., Ramos, M.H., Valéry, A., 2009. Crash tests for a standardized evaluation of hydrological models. Hydrol. Earth. Syst. Sci. 13, 1757-1764.

What Keith Beven told me when I asked him

- **a good model is one that is fit for purpose**
- **It is partly because we have many different purposes in hydrology that we have ended up with so many models –**
  - and partly because since every PhD graduate can see that it surely be possible to do better, that we have had so many theses proposing new model constructs

What Sten Bergström told me when I asked him

A good hydrological model shall:

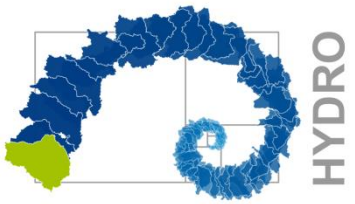
1. Be based on a sound scientific understanding of the hydrological system.
2. Perform well on a period outside the one used for calibration
3. Be transferable to different physiographic and climatological settings
4. Have a complexity that can be justified by available data and other information about the catchment
5. Have a complexity that is justified by model performance
6. Be understandable by non-specialists in hydrology

What Hubert Savenije told me when I asked him

- **The perfect model does not exist**
- **It is more appropriate to speak of models that are ‘better able to describe reality, compared to others’, than to speak of good model.**

Let us now summarize…

(*my personal summary in seven propositions*)



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Proposition 1

A 'good' model is one that gets a good (numerical) grade

A ‘good’ model is one that gets a good (numerical) grade

Many numerical criteria are available…

$$\alpha = \frac{\sigma_{obs}}{\sigma_{sim}} \qquad \beta = \frac{\mu_{obs}}{\mu_{sim}}$$

ρ – correlation coefficient

$$KGE = 1 - \sqrt{(1-\alpha)^2 + (1-\beta)^2 + (1-\rho)^2}$$

$$NSE = 1 - \frac{\sum_n \left(Q_{obs}^i - Q_{cal}^i\right)^2}{\sum_n \left(Q_{obs}^i - \overline{Q_{obs}}\right)^2}$$

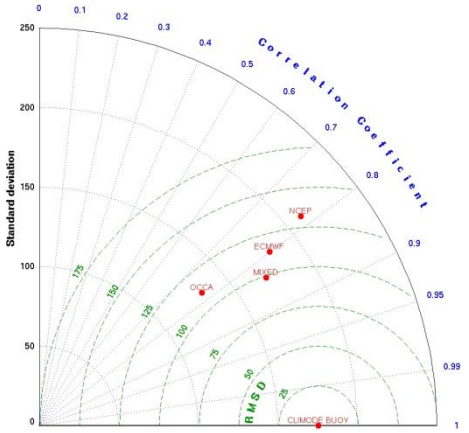
etc…

Limits of numerical criteria

- **A grade brings a relative information (an element of comparison)**
- **How to combine different grades which do not necessarily converge?**

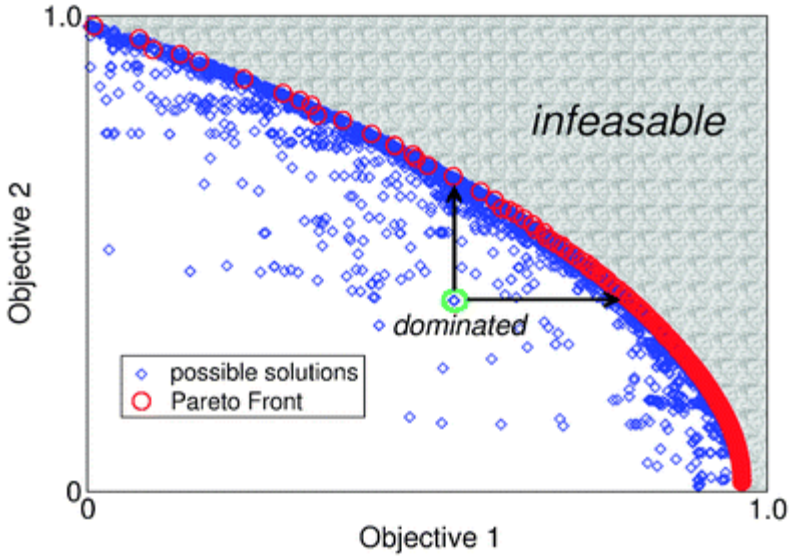
Choix multicritère

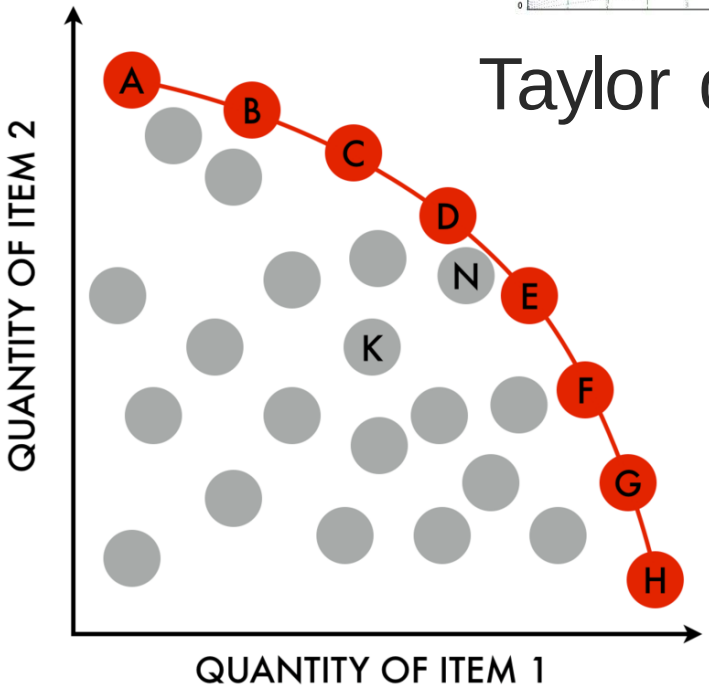
- **Multicriteria choices**



Taylor diagrams

- **Pareto fronts**





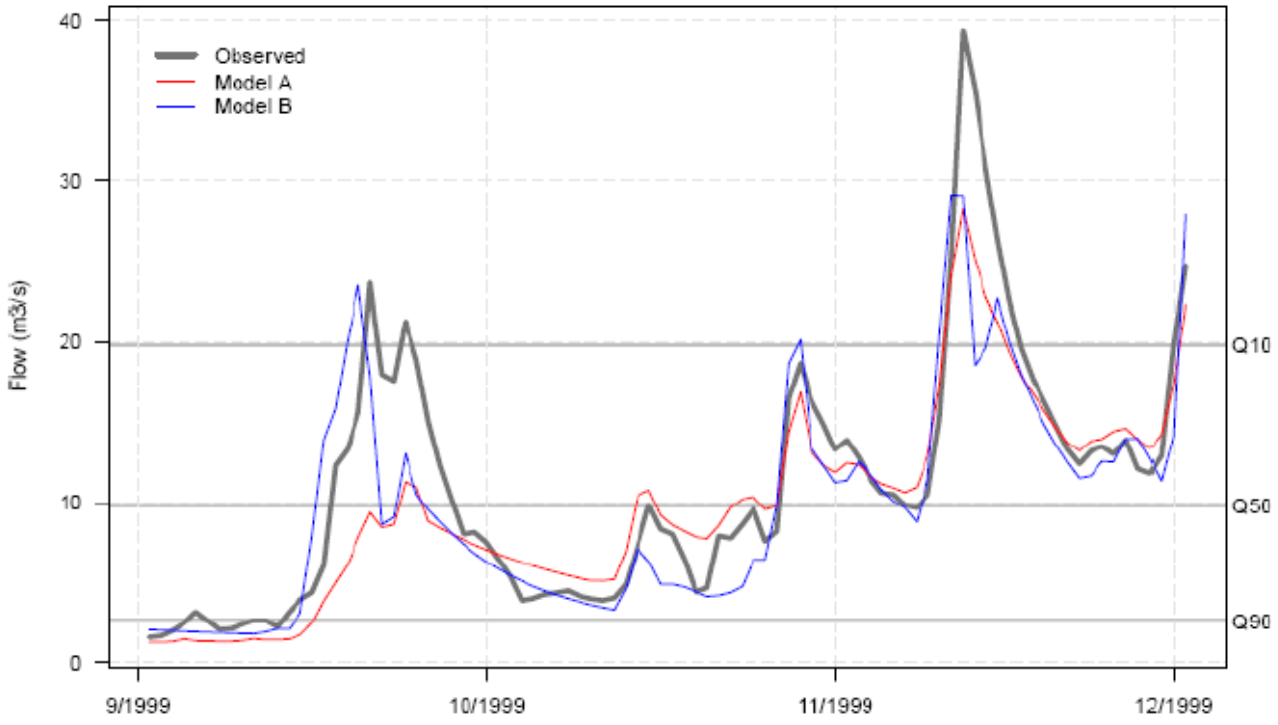
Proposition 2

A ‘good’ model is one that is deemed good by experts

Ask the expert…

- A study made in 2011

Crochemore, L., C. Perrin, V. Andréassian, U. Ehret, S.P. Seibert, S. Grimaldi, H. Gupta, J-E Paturel. 2015. Comparing expert judgement and numerical criteria for hydrograph evaluation. Hydrological Sciences Journal, 60 (3): 402-423.



Which model provides the better simulation?

- A
- B
- Equivalent

How would you rate the best simulation?

- Very Good
- Good
- Slightly Good
- Average
- Slightly Poor
- Poor
- Very Poor

Ask the expert…

- An experiment where 150 hydrologists were asked to compare
  - In relative terms streamflow simulations
  - In absolute terms the quality of models

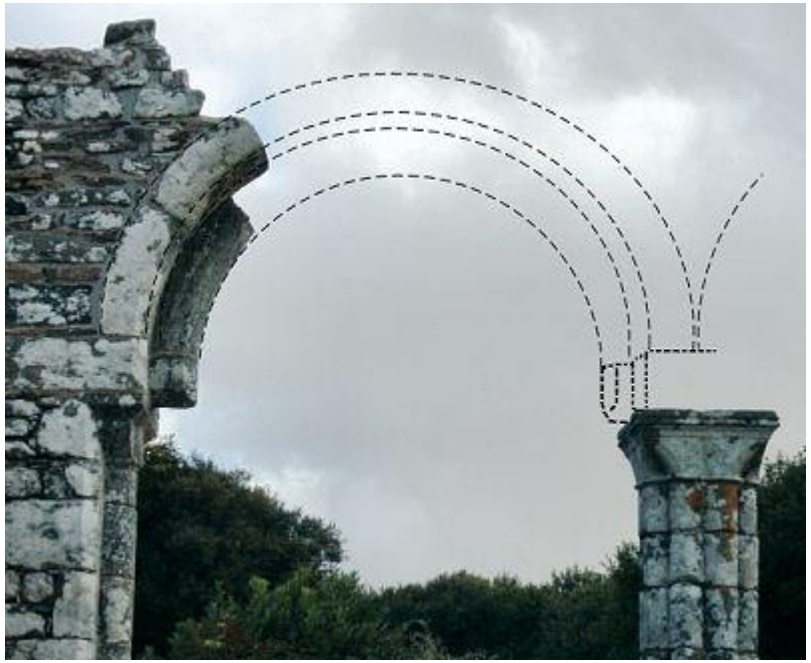
- There is no universal conclusion
  - Among hydrologists
  - Between numerical criteria
  - Between numerical criteria and expert judgement

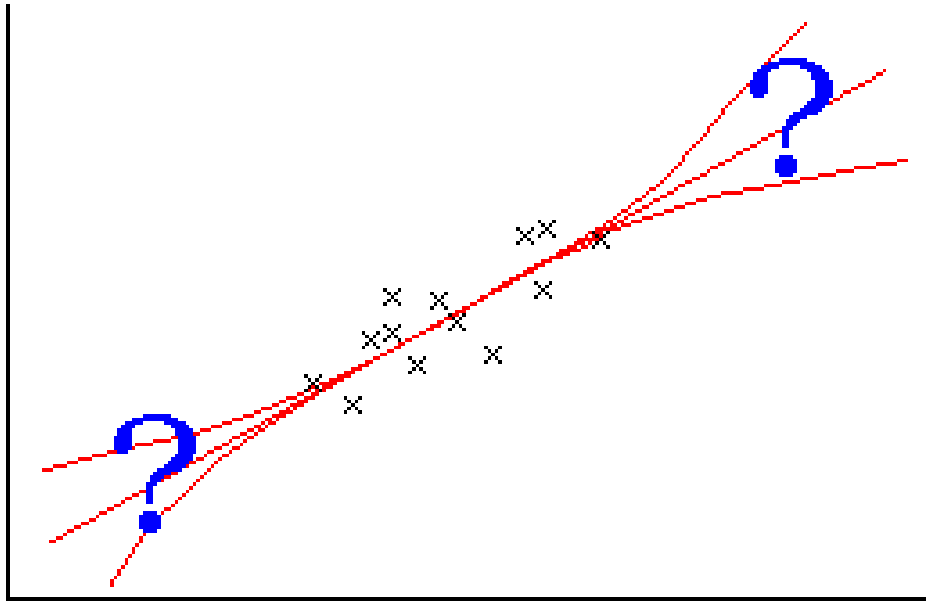
Proposition 3

A 'good' model is one that can be used in extrapolation

(robustness issue)

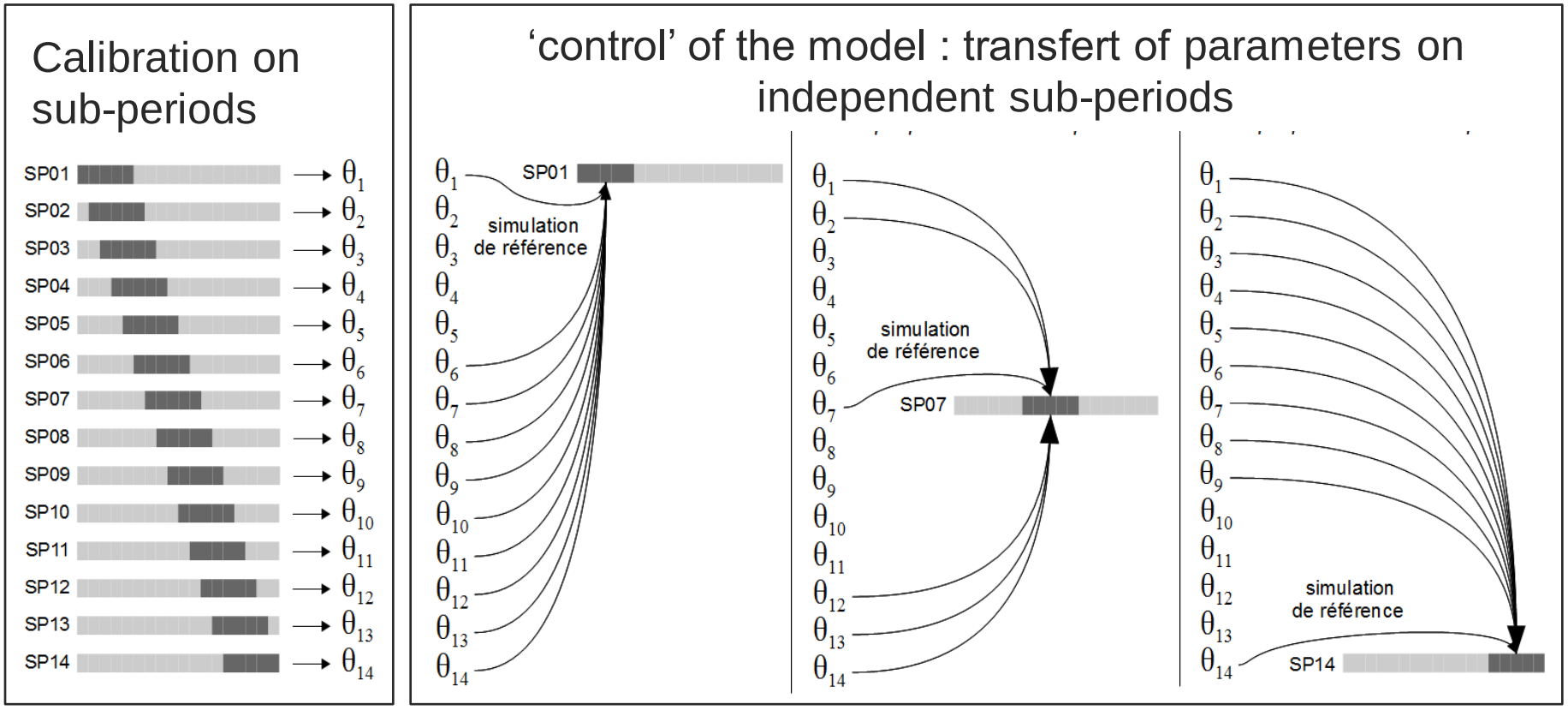
Extrapolation





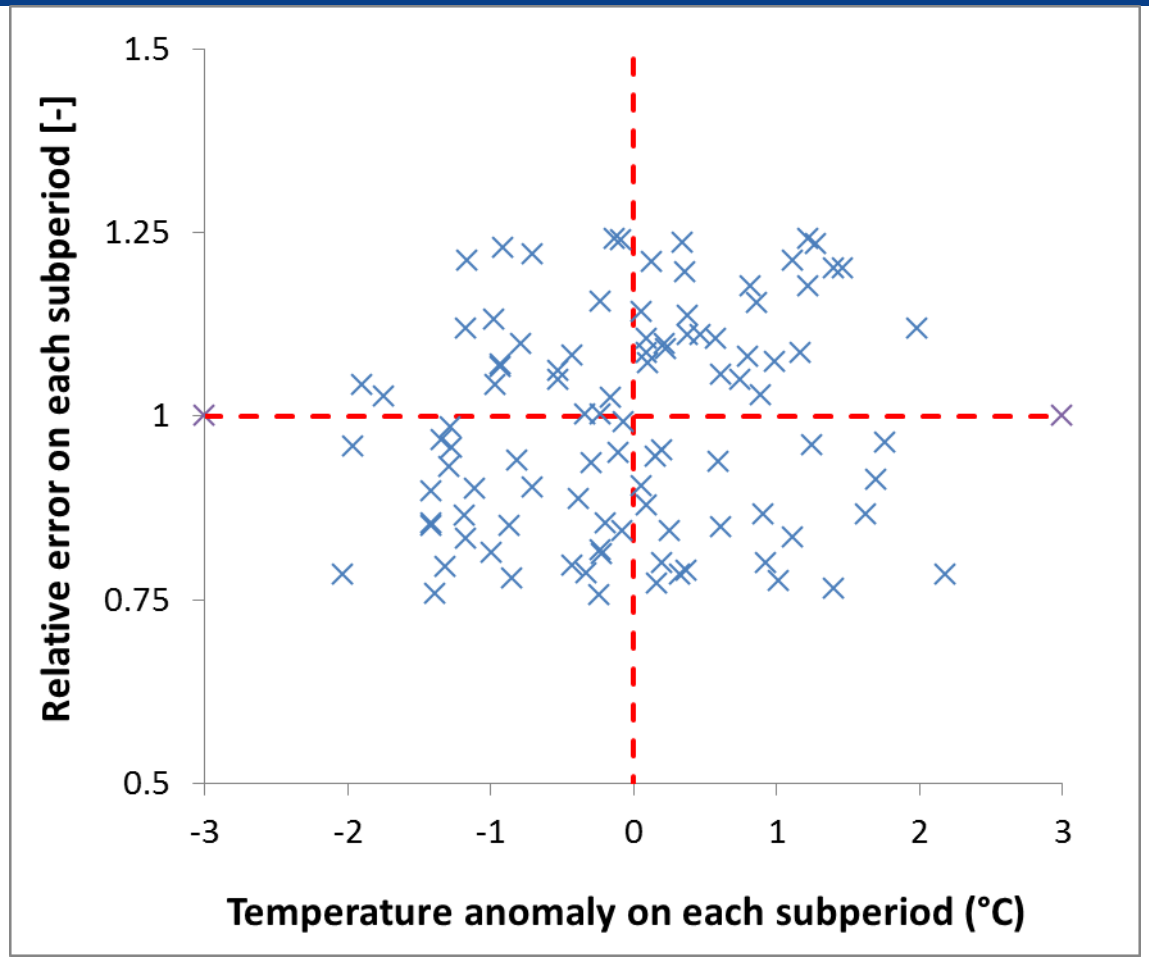
Generalized differential split-sample test to asess the extrapolation capacity of models

« generalized split-sample test » (GSST)



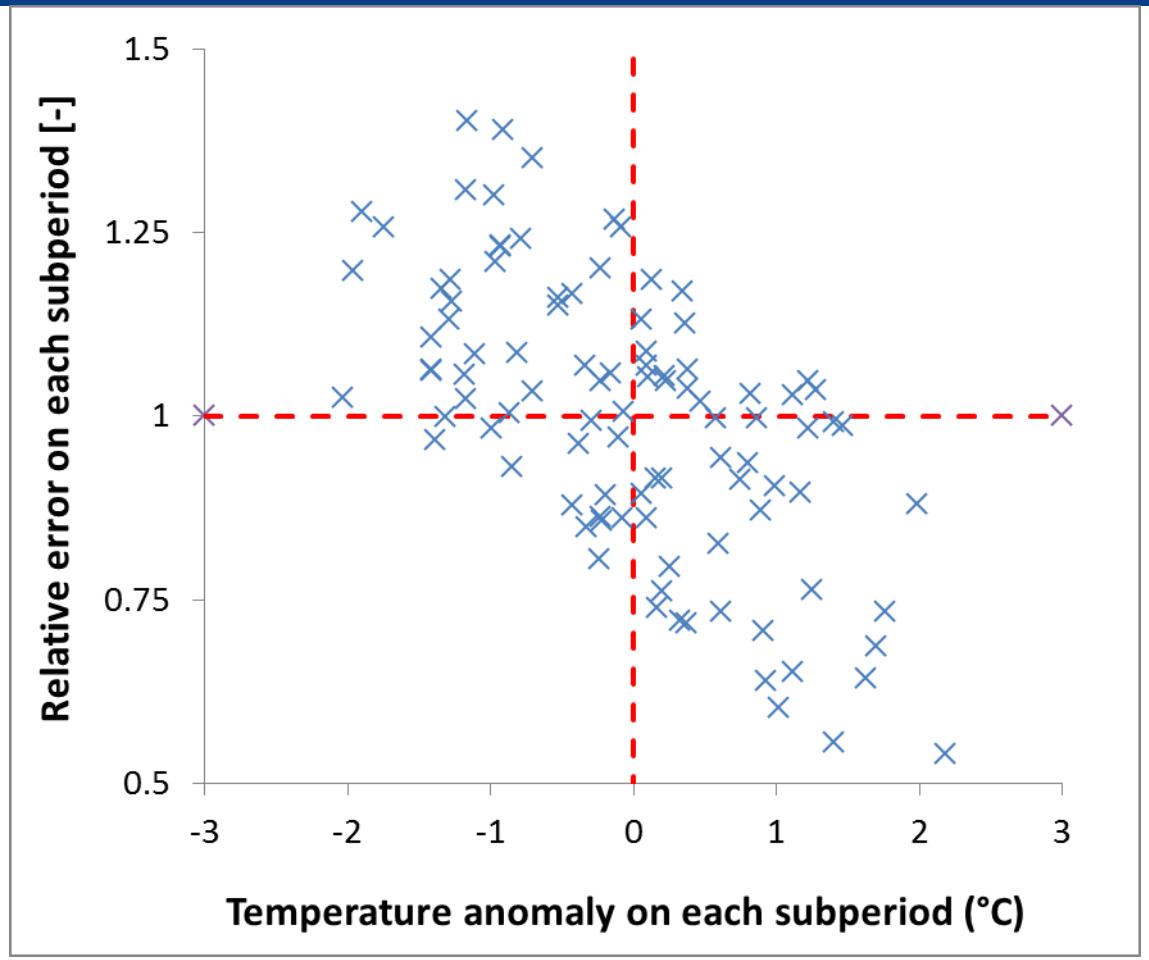
In this example: 18 years of observations, 5-year sub-periods => 90 split-sample tests

Generalized differential split-sample test to assess the extrapolation capacity of models



What we would like to see:
no correlation between model error in validation and temperature anomaly

Generalized differential split-sample test to assess the extrapolation capacity of models



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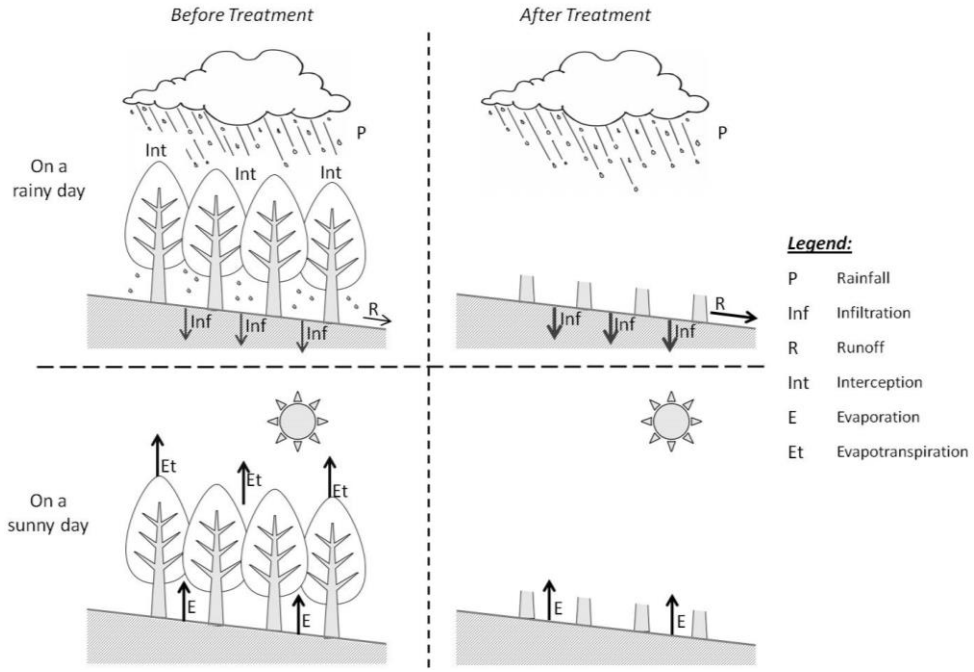
The kind of result which shows a lack of robustness:
anomalies in simulated discharge are correlated to the anomalies in temperature

This concept should be extended to ‘changing’ catchments

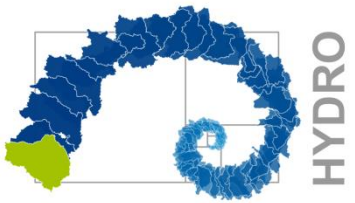


- **Thirel G., V. Andréassian, C. Perrin. 2015. Editorial: On the need to test hydrological models under changing conditions, Hydrological Sciences Journal, 60(7-8): 1165-1173.**

Proposition 4

A ‘good’ model is one that can work in degraded mode

Robustness again



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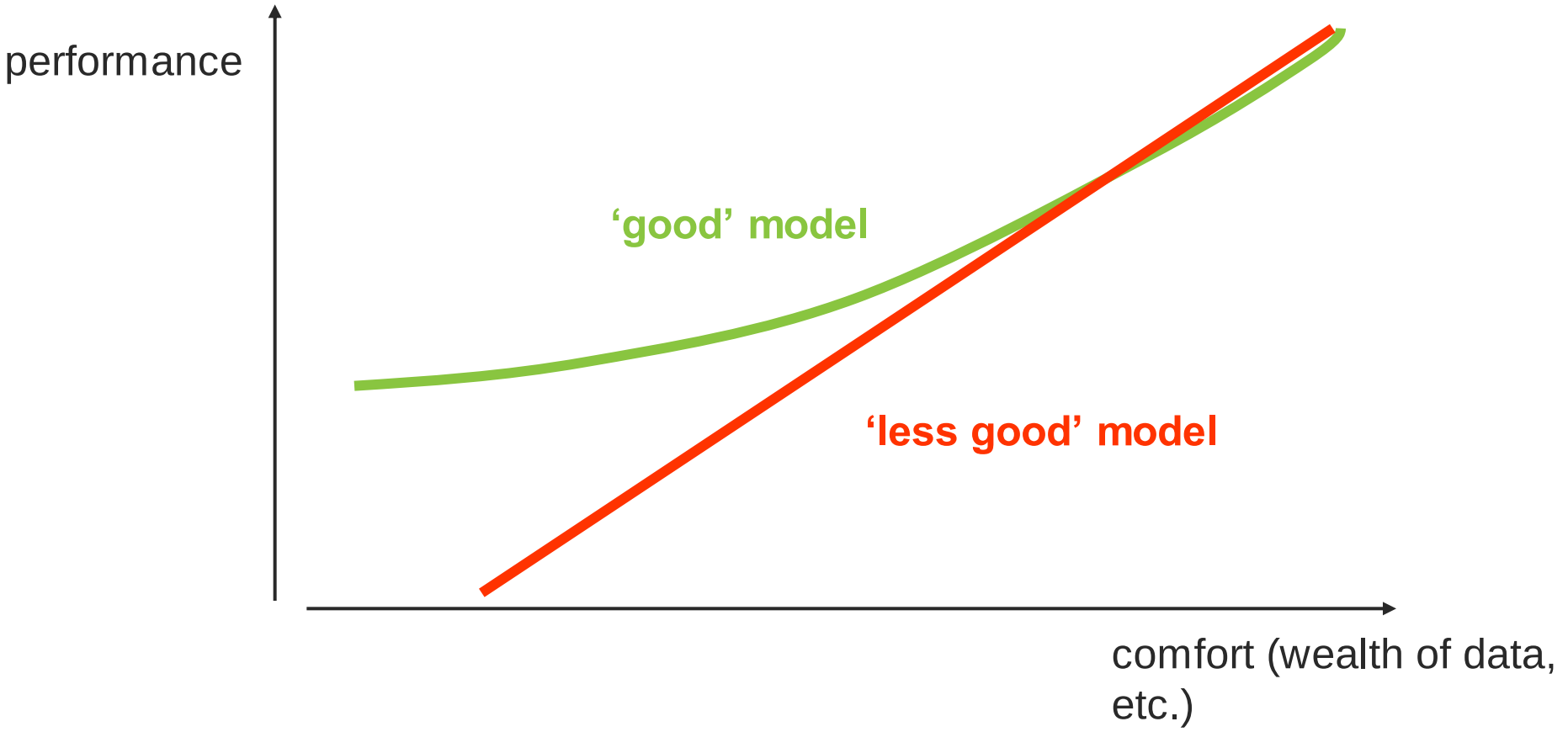

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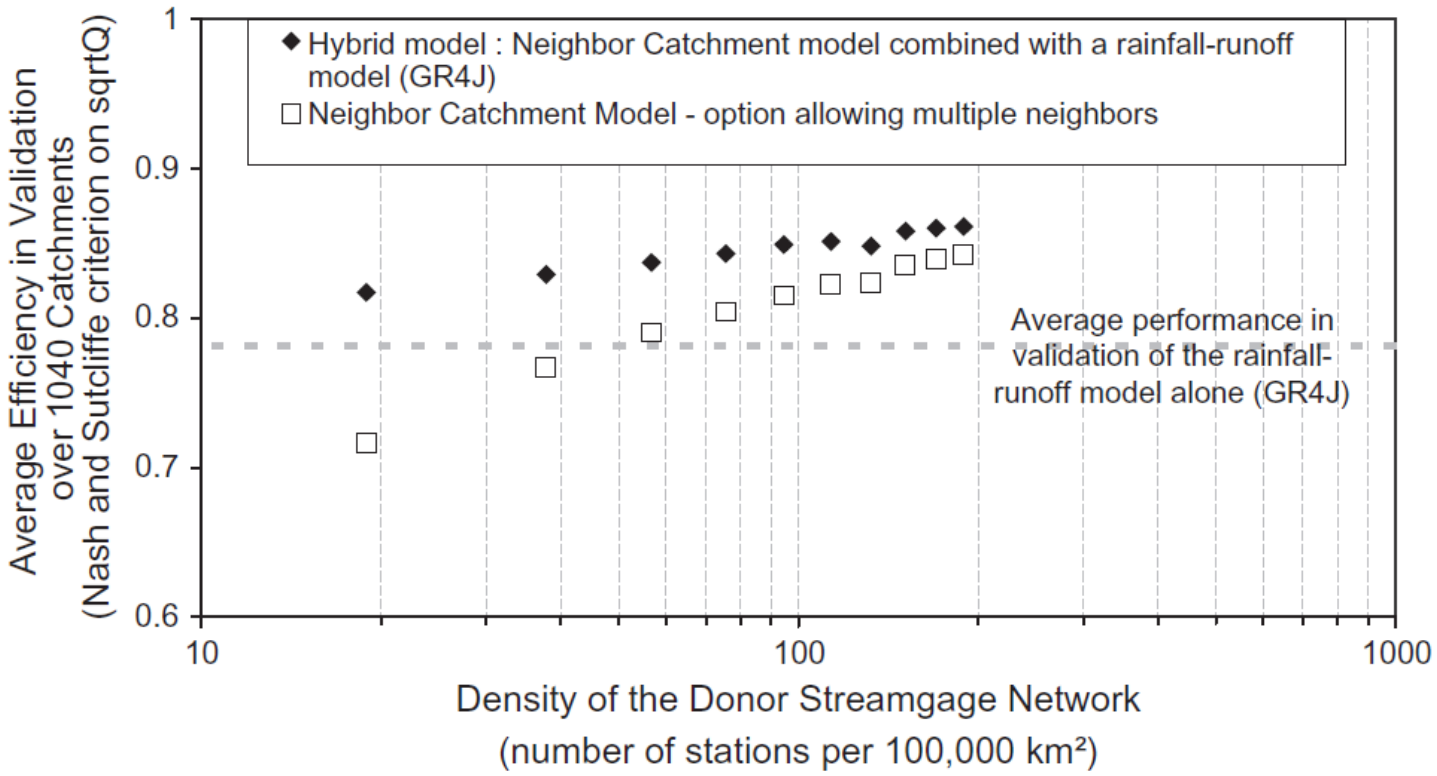
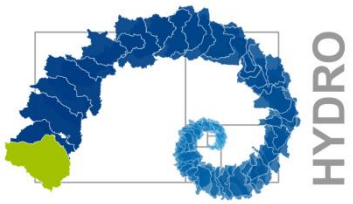


Andréassian, V., Lerat, J., Le Moine, N. and Perrin, C., 2012. Neighbors: Nature’s own hydrological models. *Journal of Hydrology*, 414-415: 49-58

Proposition 5

A ‘good’ model is one whose limits are known



A 'good' model is one whose limits are known

- **Finding the limits requires testing the model beyond them**
  - Andréassian, V., Perrin, C., Parent, E. and Bardossy, A., 2010. Editorial – The Court of Miracles of Hydrology: can failure stories contribute to hydrological science? Hydrological Sciences Journal, 55(6): 849-856.

- **Knowing the limits requires testing the model on a large data set**
  - Gupta, H.V., C. Perrin, R. Kumar, G. Blöschl, M. Clark, A. Montanari, and V. Andréassian. 2014. Large-sample hydrology: a need to balance depth with breadth. Hydrology and Earth System Sciences, 18, 463–477.
  - Andréassian, V., Hall, A., Chahinian, N. & Schaake, J., 2006. Introduction and Synthesis: Why should hydrologists work on a large number of basin data sets? IAHS Publication n°307, pp. 1-5.

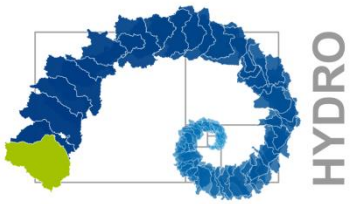
After all, what makes modern cars so safe?

‘Crash testing’ models is a necessity and the publication of these crash tests should be encouraged

Andréassian, V., Perrin, C., Berthet, L., Le Moine, N., Lerat, J., Loumagne, C., Oudin, L., Mathevet, T., Ramos, M.H., Valéry, A. 2009. Crash tests for a standardized evaluation of hydrological models. Hydrol. Earth. Syst. Sci. 13, 1757-1764.

Proposition 6

A ‘good’ model is one which is numerically sound

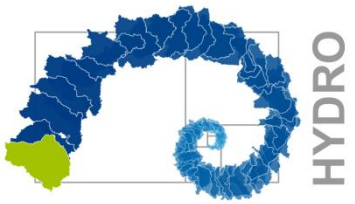


A 'good' model is one which is numerically sound

- **Most of the hydrological models require calibration (at least partially): sound numerical behavior is a prerequisite for smooth multidimensional response surface and efficient calibration**
  - Modellers should avoid thresholds
  - But integrated schemes are not as bad as publicized in the litterature

Proposition 7

A 'good' model is one which contains the right equations



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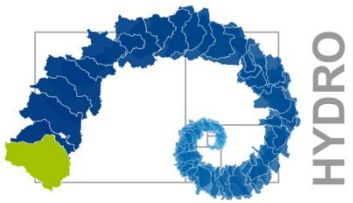
A 'good' model is one which contains the right equations

- **This proposition is debated among hydrologists (I do not suscribe to it unconditionally)**
  - « right » equations, « physically-based » equations
  - The « physical purity » of a model is an utopia: we do not know the 'true' catchment-scale equations, and upscaling physical properties from the lab-scale to the catchment (or computation unit) scale is a matter of faith
- **For equivalent efficiency, one can (should?) favour formulations which have appropriate physical justifications**

Conclusion



In lieu of conclusion

Alternative models for the Ju-52

Which model is the most faithful?

Which one flies?

Adapted from Sten Bergström, SMHI