What is the role of hydrological science in the age of machine learning?

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Scale-Relevant Theories: Holy Grail or Tilting at Windmills

1986

WATER RESOURCES RESEARCH, VOL. 22, NO. 9, PAGES 46S–58S, AUGUST 1986

Looking for Hydrologic Laws

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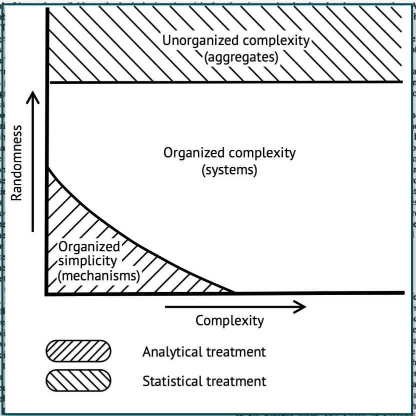
The search for regularities in hydrologic relationships is discussed against the background of the general types of predictive models used in science. The various approaches to the study of water are compared and contrasted. The ideas discussed are illustrated by examples from the development of techniques in flood hydrology and by personal conclusions on the sources for new hypotheses in flood hydrology and the possibility of their verification.

1. INTRODUCTION

1.1. *Relation of Hydrology to Science*

Fifty years ago, there was only a handful of books and a

structed to provide a prediction of system behavior to some specific accuracy and scientific theories developed to provide insight into the nature of the system operation. Though their function is different, predictive models and explanatory



required. It is important to realize that a model is not a theory and to distinguish between models that are con-

In his notable work *The Logic of Scientific Discovery*, Popper [1959] proposed falsifiability as the criterion of dermarcation of empirical science. He requires of any scientific system that 'it must be possible for an empirical scientific system to be refuted by experience.' Popper goes on to develop such principles and rules as will ensure the testability, i.e., the falsifiability of scientific statements.

Paper number 6W0295.
0043-1397/86/006W-0295$05.00

1987

Water for the Future: Hydrology in Perspective (Proceedings of the Rome Symposium, April 1987). IAHS Publ. no. 164, 1987.

Towards a new paradigm in hydrology

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ABSTRACT Hydrological scientists are faced with the problem (common to many of the field sciences) of complexity at small scales leading to relative simplicity (the hydrograph) at large scales. Little or no success

Hydrological scientists are faced with the problem of complexity at small scales leading to relative simplicity (the hydrograph) at large scales. Little or no success has been gained in relating the former to the latter

de l'évolution des théories en science. On établit une base pour un nouveau paradigme grâce à un modèle perceptuel de réaction de captation menant à un cadre conceptuel initial incorporant l'intégration spatiale et l'incertitude de la prévision.

A SHORT PATHOLOGY OF HYDROLOGICAL SCIENCE

There is an increasing body of evidence that hydrological science is in some disarray. Exhibit A: studies of the isotopic content of the waters of storm hydrographs (see for example, Sklash & Farvolden, 1979; Herrmann & Stichler, 1980; Kennedy *et al.*, 1986) have provided convincing evidence that traditional methods of "baseflow separation", still presented in recent textbooks and used in

2019

Hydrological Sciences Journal

ISSN: 0262-6667 (Print) 2150-3435 (Online) Journal homepage: https://www.tandfonline.com/loi/thsj20

Twenty-three unsolved problems in hydrology (UPH) – a community perspective

Günter Blöschl, Marc F.P. Bierkens, Antonio Chambel, Christophe Cudennec, Georgia Destouni, Aldo Fiori, James W. Kirchner, Jeffrey J. McDonnell, Hubert H.G. Savenije, Murugesu Sivapalan, Christine Stumpp, Elena Toth, Elena Volpi, Gemma Carr, Claire Lupton, Josè Salinas, Borbála Széles, Alberto Viglione, Hafzullah Aksoy, Scott T. Allen, Anam Amin, Vazken Andréassian, Berit Arheimer, Santosh K. Aryal, Victor Baker, Earl Bardsley, Marlies H.

Unsolved Problem #6: *What are the hydrological laws at the catchment scale and how do they change with scale?*

Dugo, Salvatore Grimaldi, A. B. Gupta, Björn Guse, Dawei Han, David Hannah, Adrian Harpold, Stefan Haun, Kate Heal, Kay Helfricht, Mathew Herrnegger, Matthew Hipsey, Hana Hlaváčiková, Clara Hohmann, Ladislav Holko, Christopher Hopkinson, Markus Hrachowitz, Tissa H. Illangasekare, Azhar Inam, Camyla Innocente, Erkan Istanbulluoglu, Ben Jarihani, Zahra Kalantari, Andis Kalvans, Sonu Khanal, Sina Khatami, Jens Kiesel, Mike Kirkby, Wouter Knoben, Krzysztof Kochanek, Silvia Kohnová, Alla Kolechkina, Stefan Krause, David Kreamer, Heidi Kreibich, Harald Kunstmann, Holger Lange, Margarida L. R. Liberato, Eric Lindquist, Timothy Link, Junguo Liu, Daniel Peter Loucks, Charles Luce, Gil Mahé, Olga Makarieva, Julien Malard, Shamshagul Mashtayeva, Shreedhar Maskey, Josep Mas-Pla, Maria Mavrova-Guirguinova, Maurizio Mazzoleni, Sebastian Mernild, Bruce Dudley Misstear, Alberto Montanari, Hannes Müller-Thomy, Alireza Nabizadeh, Fernando Nardi, Christopher Neale, Nataliia Nesterova, Bakhram Nurtaev, Vincent O. Odongo, Subhabrata Panda, Saket Pande, Zhonghe Pang, Georgia Papacharalampous, Charles Perrin, Laurent Pfister, Rafael Pimentel, María J. Polo, David Post, Cristina Prieto Sierra, Maria-Helena Ramos, Maik Renner, José Eduardo Reynolds, Elena Ridolfi, Riccardo Rigon, Monica Riva, David E. Robertson, Renzo Rosso, Tirthankar Roy, João H.M. Sá, Gianfausto Salvadori, Mel Sandells, Bettina Schaefli, Andreas Schumann, Anna Scolobig, Jan Seibert, Eric Servat, Mojtaba Shafiei, Ashish Sharma, Moussa Sidibe, Roy C. Sidle, Thomas Skaugen, Hugh Smith, Sabine M. Spiessl, Lina Stein, Ingelin

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Why do we lack scale-relevant theories of watersheds?

Possible Reasons:

a) **Heterogeneity Dominates:** There is simply little consistency across different watersheds, so no theory exists.

b) **Lack of Data:** We lack sufficient observations (type, scale, scope) to discover consistencies.

c) **Lack of Skill:** There is enough information in available observation data, we simply haven't made the discovery.

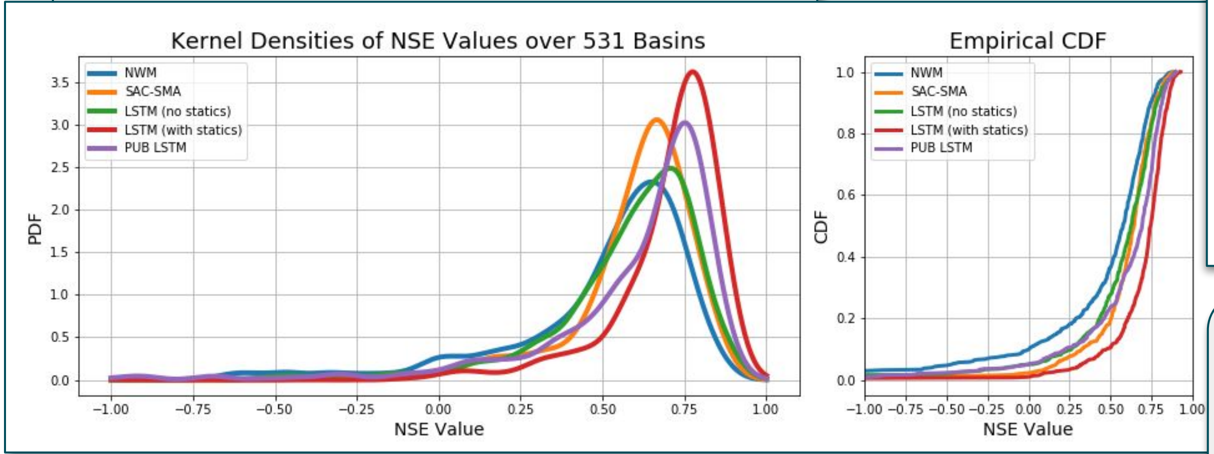
Deep Learning for PUB

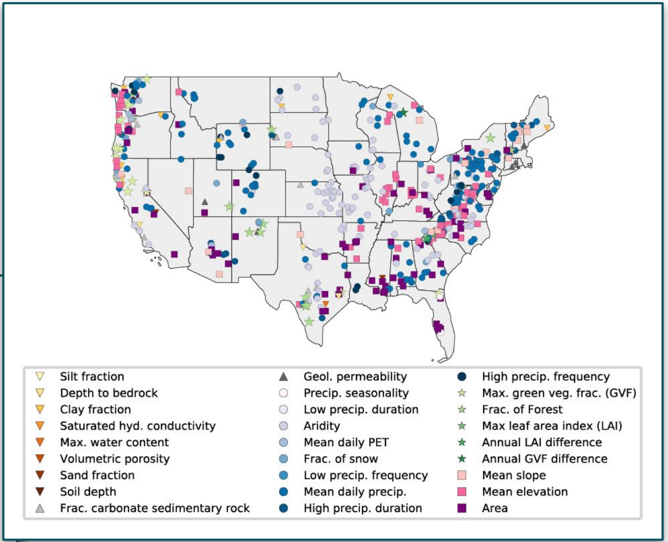
Water Resources Research

Technical Reports: Methods

Towards Improved Predictions in Ungauged Basins: Exploiting the Power of Machine Learning

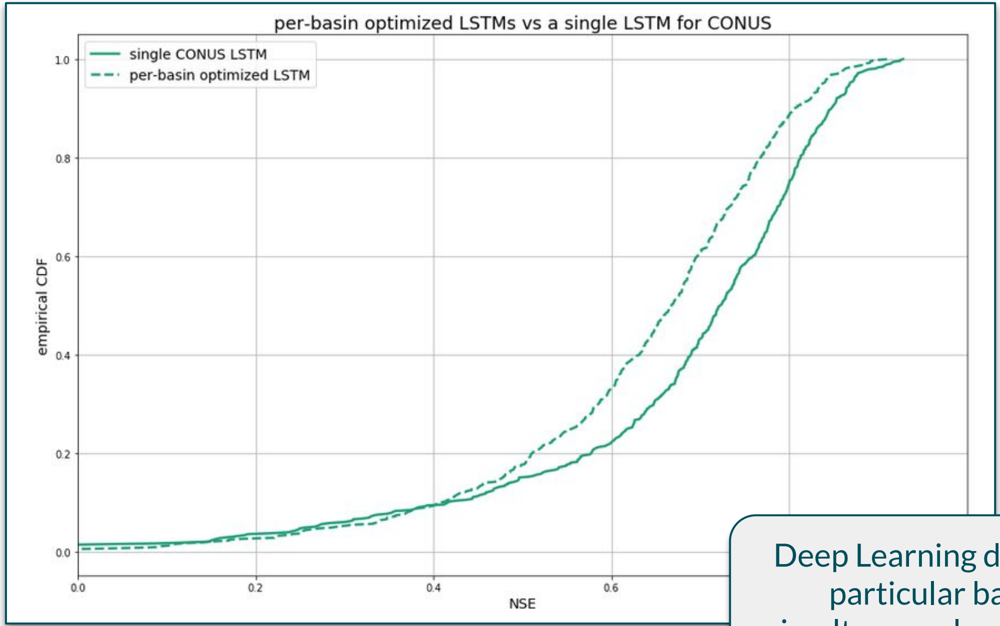
Frederik Kratzert, Daniel Klotz, Mathew Herrnegger, Alden K. Sampson, Sepp Hochreiter, Grey S. Nearing

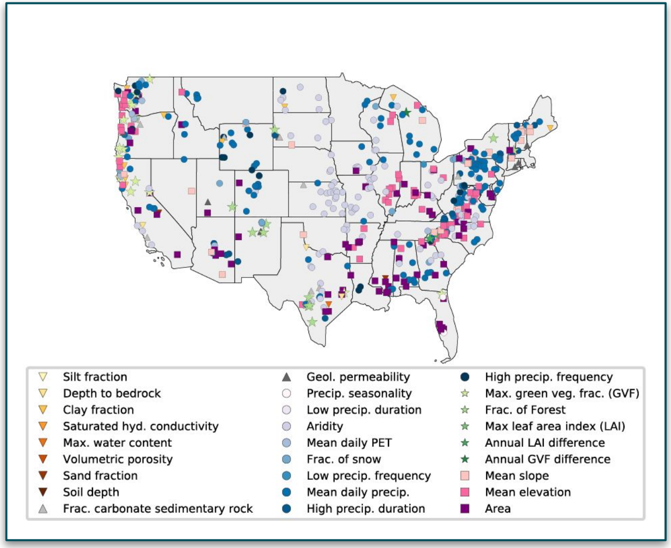




Deep learning gives better streamflow predictions, on average, in **ungauged** basins than the conceptual model calibrated to individual **gauged** basins.

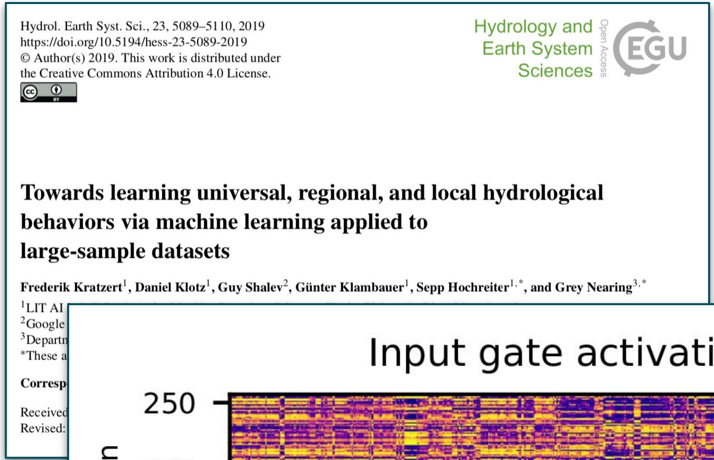
Learning a General Model





Deep Learning does **better** in any particular basin if trained simultaneously on multiple basins.

Learning Hydrologic Similarity


Hydrol. Earth Syst. Sci., 23, 5089–5110, 2019
https://doi.org/10.5194/hess-23-5089-2019

Hydrology and Earth System Sciences
Open Access
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Towards learning universal, regional, and local hydrological behaviors via machine learning applied to large-sample datasets

Frederik Kratzert[1], Daniel Klotz[1], Guy Shalev[2], Günter Klambauer[1], Sepp Hochreiter[1,*], and Grey Nearing[3,*]
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[2]Google
[3]Departn
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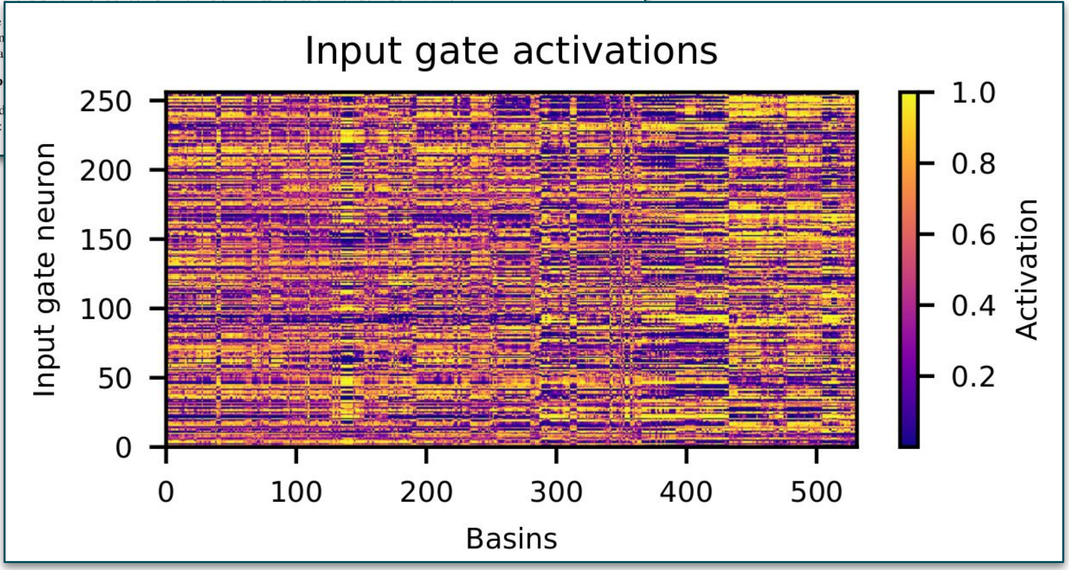

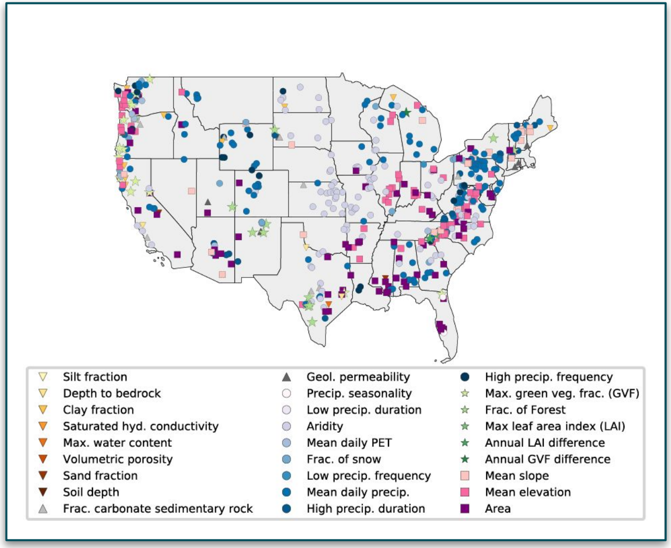

The model learns a catchment-specific 'fingerprint' based on observable catchment characteristics, and uses this to relate rainfall-runoff behaviors in different catchments.

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