Riccardo Rigon

Academic Life and Research

Riccardo Rigon

BORN	
IN	
ACTUAL POSITION	Professor of Hydrology and Hydraulic Constructions
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Contents

1. Essential Chronology

Laurea: Master in Physics at Università degli Studi di Padova, March 25 1986 (110/110). The master thesis was: "Chiral anomalies and dimensional regularization in supersymmetric gauge theories. Advisor was Prof. Mario Tonin.

Grants: 1987/88 e 1988/89. Grant from the “Guido Donegani" Foundation of the Accademia Nazionale dei Lincei (supervisor was Alessandro Marani Università degli Studi Ca’ Foscari, Venezia).

Assistant Professor of Hydrology and Hydraulic constructions, from May 27, 1993 at the Faculty of Engineering of University of Trento (tenured in 1996 after three years).

Ph. D in Hydrodynamics: At the University of Padova (Trento), 1994 (VI ciclo), under the supervision of Andrea Rinaldo. The Ph.D. dissertation was about "Principle of self-organization in the evolutive dynamics of river networks" (in Italian).

Coordinator of the research line on "Hillslope hydrology and geomorphology", of the Centro Universitario per la Difesa idrogeologica dell’Ambiente Montano (CUDAM), since 2002.

Qualified for Associate Professorship, 2003

Associate Professor of Hydrology, from January 2005 : at the Faculty of Engineering of the University of Trento.

Director of CUDAM, from January 2008- December 2018

President of the water platform of the Alpine Convention, 2013-2014

Qualified for Full Professorship, December 2013

Professor (University of Trento), January 1, 2016

2. Research

Riccardo Rigon is professor of Hydrology and Hydraulic Construction at the Department of Civil, Environmental and Mechanical Engineering at the University of Trento.

Rigon's research covered non linear geophysics, complex systems in hydrology, fractals in geophysics, distributed/process based modelling of hydrological processes, land-atmosphere interactions and the terrestrial energy budget, snow and permafrost modelling, GIS and visualization of hydrological and geomorphic processes, hydroinformatics for geosciences, and more recently modelling of evapotranspiration.

Rigon is coauthor of more than 145 papers of which 67 are journal papers, and some on conference proceedings, subjected to peer review and indexed by ISI and/or SCOPUS. He has edited a book, co-authored various e-books and many papers in proceedings and reports. Looking just at his papers will be not fair though, since the large effort he and collaborators put in producing open-source well engineered models and modelling systems, especially GEOtop - and JGrass-NewAGE, now GEOframe, and an entire free and open source GIS, JGrass, now being included in gvSigs' Horton Machine by Hydrologis.

The journal papers have closely 3400 citations with h-index 31 on ISI-Web of Science, and more than 5500 with h-index 36 on Google Scholar.

2.1. Topics and group

At present Rigon coordinates two Ph.D students, and collaborate with two spin-offs of the University of Trento (Hydrologis, Moby-GIS) that perform applied research in GIS, Snow modeling, and Urban Hydrology using products that burgeoned from his research. Rigon has been involved in several national and international research programmes.

In recent years Rigon has worked on distributed modelling of the hydrological cycle, with a focus on mountain areas. Particularly, his GEOtop model is a distributed, terrain-based, hydrological model which looks to all the hydrological fluxes in a unique consistent framework by integrating the basic mass, momentum, and energy equations. Specifically, it is currently used:

- to analyse land-atmosphere interactions;
- to study runoff productions and floods;
- to investigate the triggering of landslides and debris flows;
- to investigate snowpack evolution;
- to assess the freezing and thawing of permafrost

by several institutions around the World. **The long term goal with GEOtop is to have a tool able to cope with the thermodynamics of hydrology, including vegetation feedbacks and give, through it, a quantitative assessment to theories of optimality of resources use.**

A new model, called JGrass-NewAGE (recently renamed GEOframe system), has been developed with the use of component-based informatics, and particularly following the Object Modelling System framework, for estimating the hydrological and energy budgets at large scales. While the GEOtop model was conceived to implement the physics at small scales (some tens of square meters) and to be used for a detailed dynamic description of a catchment's hydrological behavior, JGrass-NewAGE tries to fill a gap between the hillslope scale and the catchment scale, where representation of the physics is minimized, the resolution in space and time is appropriately chosen, and the focus is on predicting emergent properties rather than system details. Field of the foreseen applications of the GEOframe system are:

- flood forecasting;
- estimation of the irrigation demand;
- global hydrology;
- studies on the impact of human infrastructures;
- estimations travel time and residence time of water in catchments;

An implementation of the GEOframe system is used for its alerts by the ARPA of the Basilicata region in Italy. Interest in soil moisture distribution evolved into studies on Richards' equation, and the formulation of a new perceptual model of water movements in the hillslope. GEOtop and GEOframe are two different products. However, in practice many of the tools are shared between the two. Future will be the contamination between the two approaches as made possible by an appropriate informatics.

A relevant part of past research dealt with the development of the geomorphological theories of the instantaneous unit hydrograph (implemented in the Peakflow model) and of a terrain-based theory of the flood forming processes. This research topic has had a new start using the recently revised travel time concepts.

Among the main research interests was the study of river networks as fractal forms created by laws of minimal energy expenditure (the optimal networks are said to be optimal channel networks, OCNs) or self-organized critical processes. Since the beginning of his research, great efforts were made by Rigon to develop new techniques and tools for the analysis of terrain data and to clarify some geomorphic laws and give a solid quantitative basis to the OCN theory. The tools that were developed now form the terrain analysis toolkit "The Horton Machine". As a matter of fact, the focus on topographic data and remote sensing gave origin to the JGrass GIS project, which eventually evolved into the implementation present in gvSIG (after GRASS, and uDig).

Since many of his activities require the use of numerical models, developed and used by many people, Rigon became interested in building models which also accomplish the requirement of being well engineered according to modern software techniques, and therefore he started thinking about "design patterns" and constitute a set of

research products parallel to papers. These models, besides implementing sound hydrology, pursue code maintainability, code literacy, easy enhancement, third parties inspection and, in summary, research reproducibility. Hopefully they represent a progress for those who use numerical models for their daily research activity.

For the foreseeable future, research activities will concentrate on the thermodynamics of soil-plant-atmosphere and interaction of the water cycle and earth systems by using and evolving GEOtop and GEOframewhich were conceived with this long term objective in mind.

2.2. Research achievements

Rigon is coauthor of:

- Papers where it is suggested that **the shape of river networks is the result of optimization of energy dissipation** and auto organization.
- Papers which assess the fractal structure of the **spatial distribution of soil moisture** (at least in some specific "dry" conditions).
- **The theory of geomorphologic dispersion** that quantifies the role of geomorphology in shaping hydrographs.
- Papers which uses 3D Richards integrators to infer consequences on hillslopes' stability.
- **A distributed model of the hydrological cycle with coupled water and energy budgets** called GEOtop which modernizes the modelling blueprint of Freeze and Harlan.
- **An Open Source GIS system**, JGrass now included in gvSIG.
- **A modelling system** called [GEOframe built upon the Object Modeling System (OMS v3) which promotes a physico-statistical view of river basins hydrology.
- A set of tools for the management and design of water supply and the urban water cycle. The first based on EPANET, the second on his own experience on the hydrological modelling and **evolving the SWMM model** into a version compatible with OMS (JSWMM).
- A theoretical assessment of **t travel time implied by Hydrological Dynamical Systems** and their **graphical representation** with a one-to-one correspondence with equations.

3. Teaching

Since 1997 Rigon has taught:

- Hydrology in the third year of the Bachelor Degree of Environmental Engineering of the Department of Civil, Environmental Engineering (up to 2013 Department of Civil and Environmental Engineering) of the University of Trento.

Since 2003 to 2019 he has also taught:

- Hydraulic Constructions at the School of Civil Engineering of the Department of Civil, Environmental Engineering (up to 2013 Department of Civil and Environmental Engineering) of the University of Trento.

Since 2020 he teaches

- Hydrological Modelling at the "Laurea Magistrale in Ambiente e Territorio"

Currently, he is creating a class about:

- Introduction to hydro-informatics (under the title of "Introduction to Java for geoscientists", and "Advanced Java for geoscientists"). For Ph.D. students in Environmental Engineering and Geosciences.
- Modelling the Hydrological cycle and earth system with the GEOframe infrastructure.

He has supervised 75 Master and Batchelor Theses, and 14 Ph.D. Theses.

Rigon's teaching activity is centred on bringing research and innovations in hydrology and hydraulic construction to his students. This is implemented with ad hoc tools for terrain and hydrologic analysis, in producing various models for the estimation of hydrological budgets, in innovating models to estimate stormwater sewer system geometries and integrating them into GIS, and using GIS to design water supply systems. All the tools have been built to be open source, user-friendly and easily accessible to students. These teaching activities are documented and, along with the tools and support material, available at:

- Hydrology
- Hydraulics Constructions
- Introduction to Java for geoscientists
- Hydrological Modelling with GEOframe
- Hydrological Modelling

Rigon also held, organised and co-organised several workshops and courses in the framework of life-long learning initiatives especially devoted to the professional development of engineers, geologists, forestry engineers and others, as listed at section 4.3 of the CV.

4. Other facts

4.1. Studies abroad

- July 1994-September 1996, while on leave from Trento, Research Associate at the Civil Engineering Department of Texas A&M University (College Station, TX 77843, U.S.A.) working with professor Ignacio Rodriguez-Iturbe.
- September 1991, January 1993, November and December 1998: periodically visiting at the Parson Laboratory of M.I.T. (Cambridge, Mass. - USA).
- July 15 - October 15, 2014, Visiting Scholar at Colorado State University, Department of Civil and Environmental Engineering, and ARS/USDA at Fort Collins, CO (USA)

4.2. Awards and Distinctions

- 1992. Arturo Parisatti Prize, awarded by the Istituto Veneto di Lettere Scienze ed Arti a Venezia (Italy) for a paper: “Is climate written into the form of channel networks ?” (in Italian)
- 1994-1998, Member of the "Surface Water" technical committee of the American Geophysical Union (AGU).
- 1996-2000, Member of the "Non linear geophysics" committee of AGU.
- 2007 Consortium of Universities for the Advancement of Hydrologic Sciences, Inc. (CUAHSI).
- Associate Editor, Geophysical Research Letters, 2008-2011
- Guest Editor, The Cryosphere, "Special Issue on Modeling the spatial dynamics of permafrost and seasonally frozen ground at diverse scales", 2011
- President of the water platform of the Alpine Convention, 2013-2014
- Part of the Scientific Committee of CINID, 2014-2018
- Committee of Società Idrologica Italiana, 2017-present
- Associate Editor of Water Resources Research, 2017-present

4.3. Main seminars, workshops, and schools organized

- June 1999. Workshop on Remote Sensing and Modelling the Earth's Surface Processes, Istituto Veneto di Scienze, Lettere ed Arti, Venezia (http://www.ivsla.unive.it)
- September 2001. Multitemp 2001, Fifth International Workshop on the Analysis of Multi-temporal Remote Sensing Images, University of Trento (organizing committee)
- July 2004. Workshop on "*Rainfall downscaling*", University of Trento, Faculty of Engineering
- September 2004. Organizing and scientific committee of the XXIX Italian Convention of Hydraulics and Hydraulic Constructions.
- February 2005, Workshop Migg2005, "Geomorphic modeling integrated in a GIS", University of Trento/Hydrologis
- February 2006, Workshop Migg2006, "Geomorphology and hydrology modeling integrated in a GIS", University of Trento/Hydrologis
- December 2008- January 2009, Workshop on "Tools and methods for mapping landslide and debris flow hazards", University of Trento/Provincial Government of Trento
- February 2010, Workshop Migg2010, "Geomorphology and hydrology modeling integrated in a GIS", University of Trento/Hydrologis
- July 2012, Workshop on Modelling Environments for Biophysical Modelling in Hydrology and Agriculture, JRC Ispra
- March 2013, Alpine Convention workshop on "Water Change in Climate Change: threat or opportunity? Changing business in changing climate", Bolzano, 4 March 2013
- March 2013, Alpine Convention workshop on "Experiences and paths in the implementation of the flood directive (2007/60/EC) in Alpine Areas", Aosta, 19 March 2013
- 14-18 October 2013, Summer School on Object Modelling System, 14-18 October 2014, University of Trento
- October 2013, Alpine Convention workshop on Water and risk management facing climate change: towards the local adaptation, Brescia, 10 October, 2013
- September, 25-26, 2014, V Water Conference of the Alpine Convention (and related events), Trento
- July 2015, Italian Ph.D Hydrology days, Trento.
- June, 27-29, 2016, Hydrology days of the Italian Hydrological Society (SII), Trento.
- July 18-21, 2016 International Summer School on modelling with OMS, Trento

- June 2018, Scientific Committee of International Congress on Environmental Modelling and Software, Fort Collins, Colorado (USA).
- January 8-18, 2019 Winter School on the GEOframe system, Trento.
- January 8-17, 2020 Winter School on the GEOframe system, Trento.

4.4. Main invited talks

- December 1993, Gilbert Club, (California University in Berkeley, Earth Sciences Department), "On landscape self-organization".
- April 1999, Conference internationale sur les risques naturales en montagne, Grenoble. "Scale ed estremes".
- August 2001, invited at Fifth International Conference on Geomorphology, Tokyo. "Exploring the complexity of mountain landscape".
- October 2004, CAHMDA-II (Princeton). "GEOtop, a distributed hydrological model for the remote sensing era".
- December 2006, AGU Fall Meeting, San Francisco, "The triggering of shallow landslides and channelized debris flows analyzed with the distributed model GEOtop-FS".
- July 2008 CUASHI Biannual meeting, Boulder Colorado, "GEOFRAME: A system for doing Hydrology by computer ".
- September 2009, Naples, First Italian Workshop on Landslide, "Analysis of saturated and unsaturated landslide triggering through the distributed hydrological model GEOtop"
- April 2010, "GEOtop, NewAGE and beyond", HS2.21/NP3.13 session, EGU General Assembly, Vienna, Austria
- September 2011, Naples, Second Italian Workshop on Landslides, "Using complex models and conceptualizations for modelling shallow landslides hydrology".
- October 2011, "GEOtop, NewAGE and beyond", INRA, Montpellier
- June 2013, "About the compromise among conceptual, mathematical and numerical tractability in some hydrological models", Annual SII meeting, To mark the 70th birthday of Ezio Todini.
- December 2013, "GEOtop, a model with coupled water and energy budgets and non-linear hydrological interactions", AGU Fall Meeting, San Francisco.
- December 2013, "GEOtop: Simulating the combined energy and water balance at and below the land surface accounting for soil freezing, snow cover and terrain effects", AGU Fall Meeting, San Francisco.
- April 2014, "Process-based modelling in Alpine catchments", EGU General Assembly, Vienna, Austria.

- August 2014, "Which Hydrological model is better ?", ARS, Fort Collins, Colorado, USA.
- October 12, 2016, "Theory and Practice of reproducible research", Perugia OGRS Conference
- January, 30, 2019, "Hydrologic modelling in a data rich world", Perugia, International Doctoral Winter School on Data Rich Hydrology

4.5. Review activities

Rigon conducts reviews for Water Resources Research, Journal of Geophysical Research, Geophysical Research letters, Advances in Water Resources, Hydrological Processes, Vadose Zone Journal, Hydrology and Earth System Sciences, Journal of Hydraulic Engineering, Journal of Hydrology, Earth Surface Processes and Landforms, Journal of Hydrometeorology, Environmental Modelling and Software, Computers and Geosciences, The Cryosphere, and other Journals.

For many years he has been invited to be part of final committees of doctoral studies by colleagues of the University of Bologna, the Polytechnic of Milan, the Polytechnic of Turin, The University of Padua, the University of Turin, University of Salerno, ETH, and INRA in Montpellier.

He has also served in the Committee for the “Habilitation Ã la Recherche" for dr. Christophe Cuddenec, at the University of Rennes.

4.6. Social networks activities and hydrological sciences dissemination

Rigon founded and manages a mailing list for communication of new positions, new open source codes, conferences, sessions, workshops, and other information called abouthydrogy (@googlegroups.com). The list has almost 4000 active subscribers worldwide.

He also founded and manages another list with the same purposes called m-hydro (@googlegroups.com) with around 2000 subscribers for the Italian community of researchers and professionals.

Since 2011 he regularly keeps a blog called "abouthydrology" (abouthydrology@blogspot.com) where he discusses about hydrological, research and academic topics. The blog has been visited since then more than one million of times. You can visit it at the link Abouthydrology.

4.7. Doctoral students supervised

During his academic carrier he has supervised 16 Ph.D. students so far, of which 12 have graduated with the following theses:

- Giacomo Bertoldi, The water and energy balance at basin scale: a distributed modeling approach, 2004
- Reza Entezarolmahdi, Parameter Estimation for Hydrologic Models, 2006.
- Emanuele Cordano (at University of Genova with Paolo Bartolini), Subsurface flow in a catchment: theoretical tools, 2006
- Stefano Endrizzi, Snow cover modelling at a local and distributed scale over complex terrain, 2007
- Silvia Simoni, A Comprehensive Approach to Landslide Triggering, 2007
- Matteo Dall'Amico, Coupled water and heat transfer in permafrost modelling, 2010
- Ageel Bushara, Hydrological simulations at basin scale using distributed modelling and remote sensing with a focus on soil moisture, 2011
- Cristiano Lanni, Hydrological controls on the triggering of shallow landslides: from local to landscape scale, 2012
- Giuseppe Formetta, Hydrological modelling with components: the OMS3 NewAge-JGrass system, 2013
- Fabio Ciervo (at University of Salerno with Mariolina Papa), Modelling Hydrological Response of structured Soils, 2015
- Wuletawu Abera (Worku), Modeling the water budget at basin scale using the JGrass-NewAGE system, 2016
- Marialaura Bancheri, A flexible approach to the estimation of water budgets and its connection to the travel time theory, 2017
- Francesco Serafin, enabling modelling framework with surrogate modeling capabilities and complex networks, May 2019
- Michele Bottazzi. Transpiration theory and the Prospero component of the GEOframe, due September 2020.

He is currently supervising 2 Ph.D. candidates,

- Niccolò Tubini. He is working on a 3D model which includes surface-subsurface water interactions in presence pf phase transition for GEOtop 4.0. Due at February 2021
- Concetta D'Amato. She is working on transpiration and travel time theories and their application inside the GEOframe system. Due at February 2023

5. Pubblications

5.1. Books (as editor)

[b1] - Marani M. and Rigon R.; editors, Hydrometeorology and Hydroclimatology, Istituto Veneto di Scienze Lettere ed Arti, Venezia, 1997

5.2. Journal papers

(Only for Journal Papers) Authors who were doctoral students or post-docs, or generically under the supervision of Rigon when the paper was first submitted are signed by "⊙". It is obviously intended that all the Authors included pro-actively participated to papers conception and writing. Papers under review are denoted by "•". Rigon's supervisors are denoted by "⋆". **Publications in boldface are may choice of 10 "must read first".**

- [j65] Rigon, Riccardo, and M. Bancheri. "Equivalences and Differences between the Hydrological Dynamical Systems of Water Budget, Travel Time and Tracers Concentration and the Legacy of Models' Topology." to be submitted to Hydrol. Processes, 2020

[j64] Bancheri, Marialaura, Riccardo Rigon, and Salvatore Manfreda. 2019. ?The GEOframe-NewAge Modelling System Applied in a Data Scarce Environment.? WATER 12 (1): 86.

[j63] Mastrotheodoros, Theodoros, Christoforos Pappas, Peter Molnar, Paolo Burlando, Gabriele Manoli, Juraj Parajka, Riccardo Rigon, et al. 2020. More Green and Less Blue Water in the Alps during Warmer Summers. Nature Climate Change 10 (2): 155-161.

[j62], Di Maggio, R., S. Dir[U+FFFD]. Callone, L. Bergamonti, P. P. Lottici, R. Albatici, R. Rigon, and N. Ataollahi. 2019. ?Super-Adsorbent Polyacrylate under Swelling in Water for Passive Solar Control of Building Envelope.? SN Applied Sciences 2 (1): 45.

[j61] - ⊙ Bancheri, Marialaura, ⊙ Francesco Serafin, and Riccardo Rigon. 2019. The Representation of Hydrological Dynamical Systems Using Extended Petri Nets (EPN). Water Resources Research 55 (11): 8895?8921.

[j60] Guenter Bloeschl, 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 Andr[U+FFFD]sian, Berit

Arheimer, Santosh K. Aryal, Victor Baker, Earl Bardsley, Marlies H. Barendrecht, Alena Bartosova, Okke Batelaan, Wouter R. Berghuijs, Keith Beven, Theresa Blume, Thom Bogaard, Pablo Borges de Amorim, Michael E. Bttcher, Gilles Boulet, Korbinian Breinl, Mitja Brilly, Luca Brocca, Wouter Buytaert, Attilio Castellarin, Andrea Castelletti, Xiaohong Chen, Yangbo Chen, Yuanfang Chen, Peter Chifflard, Pierluigi Claps, Martyn P. Clark, Adrian L. Collins, Barry Croke, Annette Dathe, Paula C. David, Felipe P. J. de Barros, Gerrit de Rooij, Giuliano Di Baldassarre, Jessica M. Driscoll, Doris Duethmann, Ravindra Dwivedi, Ebru Eris, William H. Farmer, James Feiccabrino, Grant Ferguson, Ennio Ferrari, Stefano Ferraris, Benjamin Fersch, David Finger, Laura Foglia, Keirnan Fowler, Boris Gartsman, Simon Gascoin, Eric Gaume, Alexander Gelfan, Josie Geris, Shervan Gharari, Tom Gleeson, Miriam Glendell, Alena Gonzalez Bevacqua, Mar[U+FFFD]. Gonz[U+FFFD]z-Dugo, Salvatore Grimaldi, A. B. Gupta, Bjrn Guse, Dawei Han, David Hannah, Adrian Harpold, Stefan Haun, Kate Heal, Kay Helfricht, Mathew Herrnegger, Matthew Hipsey, Hana Hlav[U+FFFD]kov[U+FFFD]lara 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 Kohnov[U+FFFD]lla 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 Mah[U+FFFD]lga Makarieva, Julien Malard, Shamshagul Mashtayeva, Shreedhar Maskey, Josep Mas-Pla, Maria Mavrova-Guirguinova, Maurizio Mazzoleni, Sebastian Mernild, Bruce Dudley Misstear, Alberto Montanari, Hannes Mller-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, Mar[U+FFFD]. Polo, David Post, Cristina Prieto Sierra, Maria-Helena Ramos, Maik Renner, Jos[U+FFFD]uardo Reynolds, Elena Ridolfi, Riccardo Rigon, Monica Riva, David E. Robertson, Renzo Rosso, Tirthankar Roy, Jo[U+FFFD].M. S[U+FFFD]ianfausto 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 Steinsland, Ulrich Strasser, Bob Su, Jan Szolgay, David Tarboton, Flavia Tauro, Guillaume Thirel, Fuqiang Tian, Rui Tong, Kamshat Tussupova, Hristos Tyralis, Remko Uijlenhoet, Rens van Beek, Ruud J. van der Ent, Martine van der Ploeg, Anne F. Van Loon, Ilja van Meerveld, Ronald van Nooijen, Pieter R. van Oel, Jean-Philippe Vidal, Jana von Freyberg, Sergiy Vorogushyn, Przemyslaw Wachniew, Andrew J. Wade, Philip Ward, Ida K. Westerberg, Christopher White, Eric F. Wood, Ross Woods, Zongxue Xu, Koray K. Yilmaz Yongqiang Zhang (2019) Twenty-three unsolved problems in hydrology (UPH) ? a community perspective, Hydrological Sciences Journal, 64:10, 1141-1158, DOI: 10.1080/02626667.2019.1620507

[j59] - ☉Bancheri, Marialaura; ☉Serafin, Francesco; ☉Bottazzi, Michele; Formetta, G. and R. Rigon; The design, deployment, and testing of kriging models in GEOframe with SIK-0.9.8, Geoscientific Model Development, Volume: 11 Issue: 6 Pages: 2189-2207, 2018

[j58] Pullens, J. W. M.; Sottocornola, M.; Kiely, G.; Gianelle, D; Rigon, R., Assessment

of the water and energy budget in a peatland catchment of the Alps using the process based GEOtop hydrological model, Journal of Hydrology Volume: 563 Pages: 195-210, 2018

[j56] ⊙ Abera, W; Formetta, G.; Brocca, L.; Rigon, R.; Water budget modelling of the Upper Blue Nile basin using the JGrass-NewAge model system and satellite data, 21, 3145-3165, 2017, HESS, https://doi.org/10.5194/hess-21-3145-2017

[]55] - ⊙ Abera, W; Formetta, G.; Borga, M.; Rigon, R.; Estimating the water budget components and their variability in a Pre-Alpine basin with NewAge-JGrass, Advances in Water Resources, Vol 104, 37-54, 2017

[j54] - Formetta, G., ⊙ Bancheri M., Rigon R., Performance of site-specific parameterizations of longwave radiation, Hydrol. Earth Syst. Sci., 20, 4641-4654, 2016, http://www.hydrol-earth-syst-sci.net/20/4641/2016/ doi:10.5194/hess-20-4641-2016

[j53] - **Rigon R., ⊙Bancheri M., Green T., Age-ranked hydrological budgets and a travel time description of catchment hydrology, in publication, Hydrol. Earth Syst. Sci., 20, 4929-4947, 2016 http://www.hydrol-earth-syst-sci.net/20/4929/2016/ doi:10.5194/hess-20-4929-2016**

[j52] - ⊙Abera, W.W., Brocca L, and Rigon R. (2016). Comparative evaluation of different satellite rainfall estimation products and bias correction in the Upper Blue Nile (UBN) basin. Atmospheric Research, 178-179, 471?483. http://doi.org/10.1016/j.atmosres.2016.04.017, 2016

[j51] - Fatichi,S; Vivoni e.R.; Ogden F.L.; Ivanov V.Y.; Mirus,B; ?Gochis, D; Downer C.W.; Camporese, M; Davison J.H., Ebel, B; Jones, N; Kim, J., Mascaro, G; Niswonger, R; Restrepo, P.; Rigon, R.; Shen, C.; Sulis, M.,Tarboton, D.; An overview of current applications, challenges, and future trends in distributed process-based models in hydrology, *Journal of Hydrology*, 537 (2016) 45-60, 2016

[50] - Hingerl L., Kunstmann H., Wagner S., Mauder M., Bliefernicht, J; Rigon, R., High Resolution Joint Water and Energy Balance Observation and Modeling in a Prealpine Environment, *Hydrol. proc*, published on line, 10.1002/hyp.10893, http://onlinelibrary.wiley.com/doi/10.1002/hyp.10893/pdf, 2016

[j49] - ⊙Formetta G., S. Simoni, J. W. Godt, N. Lu, and R. Rigon (2016), Geomorphological control on variably saturated hillslope hydrology and slope instability, *Water Resour. Res.*, 52, 4590?4607, doi:10.1002/2015WR017626.

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5.4. E-Books and Manuals

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[eb12] - De Col F., Bosoni A., Righetti D., Antonello A., Franceschi S., Rigon R., La progettazione di una rete di acquedotto con i Netools (Epanet integrato in uDig), Università di Trento, 2014

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[eb6] Rigon R., Formetta G., Zini M., Franceschi S., Antonello A., La Horton Machine, Università di Trento, 2014

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[eb2-b] Ghesla, E. and R. Rigon, a Tutorial for the Management of Digital Terrain Models, pg. 131, University of Trento, Department of Civil and Environmental Engineering, ISBN 10: 88-8443-155-7, 2006

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5.5. Publications for educational purposes

All of these are available from http://abouthydrology.blogspot.com, except where differently specified.

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[d2] - Rigon R., Real books di Idrologia (Slides Collection) , Università di Trento, 2012-2015

[d1] - Rigon, R. e A. Marani, Matematizzazione e simulazione della natura. Introduzione ai modelli matematici per l'ambiente, in: Un punto per l'ambiente: itinerari educativi, Il Sistema ambiente, pag. 205-37, Editore: Lorenzo Bonometto, Assessorato alla ecologia della Provincia di Treviso, 1992.

5.6. Main Reports in Projects

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[rep08] - R. Rigon, State of the art of prediction techniques, IRASMOS EU Project Deliverable 1.3, 2007

[rep07] - Rigon R. (Ed), State-of-the-art models: their transferability and model application, IRASMOS EU ProjectDeliverable 1.2, 2007

[rep06]- Rigon R., Rickenmann D., Catalogue of causes and triggering thresholds (Ed), IRASMOS EU Project Deliverable 1.1, 2007

[rep05] - R. Rigon, A. Bellin, L. Forlin, H. Fowler, S. Blenkinsop, Testing of climate change scenarios on a case-study catchment using different methodologies, Deliverable C2.4 AQUATERRA EU Project, 2005

[rep04] - R. Rigon, C., Park H., Beyer C., Berger C. and Kolditz O., Travel time statistics of a passive tracer in the vadose zone, Deliverable C2.4 AQUATERRA EU Project, 2005

[rep03] - R. Rigon, a cura di, Studio delle emissioni di CO2 in Trentino, in Studio della Sostenibilit'a dell'ambiente in Trentino, a cura di C. Diamantini, 2005

[rep02] - Cozzini, A., Rigon R. HORTON: un insieme di programmi open source per l'analisi geomorfologica quantitativa dei bacini. Dipartimento di ingegneria civile ed ambientale - CUDAM. 1999

[rep01] - Rigon R. Trento_p: Manuale d'uso. Dipartimento di ingegneria Civile ed Ambientale. 1999

6. Software

This list software packages of major complexity and industrial quality, available as open source (usually GPL v3), and refereed in research papers, blossomed from Rigon's research are usually developed from a community of users and developers.

[s5] Former JGrass-NewAGE (since 2008), now GEOframe: it represents the growing collection on OMS v components for the modelling of the hydrological cycle at large scale, and includes also tools for the spatial extension of hydrometeorological variables. They are available at Github Geoframe repository. Extensive documentation can be found at Winter School on GEOframe

[s4] GEOtop (since 1997): it is a processes based, finite volumes, model of the hydrological cycle
GEOtop code is available at GEOtop repository. Extensive documentation is available at GEOtop essentials.

[s3] The Horton Machine (since 1997): it is quite complete collection of OMS modules for the treatment and analysis of Digital Elevation Models
Available at Horton Machine.

[s2] Jgrass (since 2002): it is a full featured GIS system built to support the hydro-geomorphological research of the group since the early 2000s. Recently it has been integrated in uDig.
Available at: LongTerm JGrass repository

[s1] Trento$_p$ (since 2000): It is a model for the estimation of flood peaks in urban areas and for the design of culverts and sewers. A new version is being developed and integrated with SWMM. It can be found at JSWMM repository

7. Research projects

Rigon has participated in more than thirty research projects of national and international interests (with a total budget of more than one million euros over the last ten years) where he had the role of local principal investigator or a specific independent task to accomplish. In 2012-2014 Rigon suspended the search for Research Projects, in order to properly dedicate himself to the Presidency of the Water Platform of the Alpine Convention. This activity was financed by the Province of Trento, in accordance with the Italian Ministry of the Environment.

7.1. As Local Principal investigator

[p1] 1997-1998 Local PI of the national project MURST 40% of the National Group “Urban Hydrology".

[p2] 1999-2000 - Local PI of COFIN 98 "Defence of urban areas from stormwater pollution".

[p3] 2000-2001 - Local PI COFIN 99 of "Analysis of structures of interests in the field of environmental fluid mechanics".

[p4] COFIN 2001 (2002-2003)- Interaction Climate-Soil-Atmosphere-Vegetation and effects on extreme hydrological events.

[p5] COFINLAB - In 2001 MIUR financed some centres of excellence in science and technology. Among these, CUDAM (Centro Universitario per la Difesa idrogeologica dell’Ambiente Montano- Center for Advanced studies on hydrogeological hazards in mountains areas) is one of the four financed in our field (including meteorology and forestry). Rigon is the principal investigator of the first research line : Hillslope hydrology and the generation of sediment in mountain catchments

[p6] 2002-2004 - TIDE (contract no.: EVK3-CT-00064 5th EU RTD framework, extension: 2002-2004). In the TIDE project the University of Trento group, coordinated by Rigon, developed and tested a model of the basins flowing into the Venice Lagoon. GEOTOP, and other models (VIC - the variable infiltration capacity model) were used.

[p7] BASIC RESEARCH FUNDING FROM University of Trento. LAND ATMOSPHERE INTERACTIONS (duration:2003-2004). Together with the group of atmospheric physics, Rigon shared a project for the study of the energy balance at the Earth surface. The surface hydrology group essentially developed the first version of the energy balance of the GEOtop model.

[p8] COFIN 2005 (extension 2006-2007) - It is the natural follow up to COFIN 2001 and 2003 with the development of a more physical parametrization of atmospheric interactions. It was entitled: The development of the GEOTOP model and its application to the study of the soil-vegetation-atmosphere interactions."

[p9] ASI (Italian Space Agency) 2004- Progetto Modellazione e previsione delle frane in funzione della protezione civile, mediante l'uso di dati telerilevati (On modelling and forecasting landslides for civil protection purposes with the aid of remotely sensed Earth Observations), preliminary project financed by ASI.

[p9] BASIC RESEARCH FUNDING FROM the University of Trento: CHARACTERIZATION OF THE EFFECT OF PARAMETER UNCERTAINTY in hydrological modelling (June 2005- June 2006). The goal was to associate confidence intervals to hydrologic forecasting, especially regarding flood forecasting and landslide triggering.

[p10] IRASMOS (2006-2008), which stands for Integral Risk Management of Extremely Rapid Mass Movements (http://irasmos.slf.ch/). Rock avalanches, debris flows, and snow avalanches are landslide and landslide-related processes, subsumed under the term extremely rapid mass movements. These processes pose varying degrees of risk to land use, infrastructure, and personal security in many mountainous regions. Despite increasing efforts to quantify the risk in terms of potential damage or loss of life, most previous studies have achieved partial rather than total risk solutions. IRASMOS addresses these shortcomings by reviewing, evaluating, and augmenting methodological tools for hazard and risk assessment of extremely rapid mass movements. Results to be synthesized in strategies proposed within the framework of an Integral Risk Management (IRM) in selected European mountain catchments, targeted to equally address measures pertaining to landslide- and snow-avalanche disaster prevention, response, and rehabilitation.

[p11] 2007-2009 MORFEO (http://www.morfeoproject.it/). A project for the forecasting of landslides for civil protection actions, financed by the Italian Space Agency (ASI).

[p12] 2006-2008 - Monitoring of four Alpine Basins to detect the soil moisture evolution in Trentino. Financed by the Autonomous Province of Trento, and connected to the MORFEO project.

[p13] PermaNET(2009-2011) at http://www.permanet-alpinespace.eu/home.html. The PermaNET project has produced an alpine-wide permafrost monitoring network including an information system and selected monitoring sites, and a permafrost map for the entire Alpine Space. It has also developed a common strategy for the consideration of permafrost in risk and water resources management. The transnational cooperation (Austria, France, Germany, Italy and Switzerland) in aggregation of existing and collection of new data to produce a common permafrost dataset has been aimed at reducing costs for the adaptation of governance practices to specific effects of climate change.

[p14] HydroAlp (2011-2014). The research project HydroAlp aims to quantify the local scale effects of climate change on the water cycle in Alpine regions. Thus, an innovative modelling framework, which accounts for the effects of basin morphology on runoff production and the interactions between soil/vegetation dynamics and climate in an integrated way and that can be applied at the scale of Alpine basins, will be developed.

[p15] (2012-2013) Hillslope hydrology of volcanic areas. The project, financed by the University of Calabria, aims to use the tools developed at the University of Trento

at sites of the Campania Region where soil contains pumice and is strongly layered.

[p16] CLIMAWARE (2015-2016) It is a University supported project of which Rigon is the PI. It involves thirteen researchers from five Departments of the University of Trento. The proposal focuses on the interactions between climate change and human activities related to water, with a holistic view embracing physical, social and economic processes. It will consider, in particular, changes in water cycle components related to extremes and their implications in contiguous sectors. Extremes include floods and land instabilities triggered by extreme precipitations, such as debris-flows and snow avalanches, but also different stress factors threatening the integrity of freshwater services, with adverse effects on agriculture, tourism, and energy production. The project aims to develop new paradigms, approaches and tools in order to cope with the non-stationarity of water cycle processes and to study the entanglement between the physical processes and human activities.

[p17] PRIN 2017 - WATZON (2019-2021) The project will create a new network of study sites in Italy (Critical Zone study sites) representative for different climatic, physiographic and vegetation conditions in the Mediterranean area, including grassland, forested and agricultural ecosystems. High-resolution and detailed experimental data and observations will be collected in a consistent way across all study sites in order to identify water pools potentially involved in ecohydrological water exchanges and fine-study root water uptake dynamics. The high-quality data collected in the field and the experimental results will serve as a basis to implement and apply new-generation, robust, reliable and realistic ecohydrological models aiming at assessing water mixing and exchange mechanisms between subsurface reservoirs, vegetation and atmosphere at the root-plant scale and the stand and catchment scale. The role of Trento is to build the models that other Units will use and contribute to experimental sites through the collaboration with Giacomo Bertoldi of EURAC Research.

As participant

[pp1] 2000-2002 - THARMIT, standing for "Torrents hazard control and risk mitigation", contract no.: EVG1- CT-1999-00012. The main aim of the project was to increase the control of torrent hazard with a deeper understanding of practical tools and methodologies for risk assessment and mitigation, focusing on prevention and reduction of risks.

[pp3] TREND (extension: 2002- September 2003) a project of the Department of Civil and Environmental Engineering of the University of Trento, in collaboration with the Provincial Agency for Environmental Protection (APPA). The research goal was to study the evolutive trend of nutrient and water balance in Alpine lakes. The principal investigator of TREND was professor Paolo Bertola. Marco Ragazzi worked on water quality, Maurizio Righetti studied the lake hydrodynamics and Riccardo Rigon the hydrological balance.

[pp4] 2003-2004 PROVINCIA AUTONOMA DI TRENTO: PAT-VIPI (Valutazione Integrata del Pericolo Idrogeologico nelle conoidi alpine - integrated evaluation

of the hydrogeological hazard in Alpine alluvial fans). The project worked to build a common conceptual and computer framework to study the hydrological hazards in mountain areas with special focus on alluvial fans. This framework aimed to integrate knowledge coming from hydraulics, hydrology, urban planning and economics. It also worked to coordinate the actions of the different players in the field: not only the scientists who need to represent the results of their analysis in a simple but consistent manner but also the regional agencies or local authorities that produce and pre-process the data sets.

[pp5] June 2000-June 2002 - The “CONOIDI" Project for the River Po Authority: Description and interpretation of flooding, intense sediment transport, hydrogeological hazard and alteration of the natural conditions associated with Alpine alluvial fans and their catchments. Estimation of the risk for inhabitants, settlements and infrastructures. The title “CONOIDI" refers to alluvial fans, and during the project ten of the 500 alluvial fans in the Alps were analyzed.

[pp5] PROGETTO SPECIALE SALVAGUARDIA DEI CONOIDI (Special project for the protection of alluvial fans), CATCH-RISK (duration: 2003-June 2004). The first objective of the project was to create a shared approach for the definition of hydrogeological risk scenarios in Alpine catchments and on alluvial fans. To achieve this all aspects of hydrogeological hazards affecting a catchment were analyzed, in particular: flooding; droughts and aquifer depletion; landslides, such as rockfalls, soil slips and debris flows. This led to the evaluation of hazard and risk, both in the catchment and on the alluvial fans. The final objective was to provide guidelines to professionals and administrators to support decision-making in the improvement of water management, planning land use and protective measures, and risk management.

[pp6] AQUATERRA (2004-2008), an integrated project of the 6th EU RTD Framework Programme that aimed to provide the scientific basis for improved river basin management through a better understanding of the river-sediment-soil-groundwater system as a whole, by integrating both natural and socio-economic aspects at different temporal and spatial scales. This should be applicable to European contexts facing modifications or changes due to Climate Change, Land Use or other perturbations (such as pollution). Soil-water management at catchment and river basin scales requires the identification of the relevant processes and the quantification of associated parameters, and the development of numerical models of the groundwater-soil sediment-river system to identify adverse trends in soil functioning, water quantity and quality.

[pp7] GLOBAQUA - http://www.globaqua-project.eu/en/home/ (2014-2019) GLOBAQUA (Managing the effects of multiple stressors on aquatic ecosystems under water scarcity) has assembled a multidisciplinary consortium to study the interaction of multiple stressors within the frame of strong pressure on water resources. GLOBAQUA assesses the effects of water scarcity on aquatic ecosystems by focusing on six river basins (Ebro, Adige, Sava, Evrotas, Anglian and Souss Massa). These basins encompass a rich set of socio-ecological conditions and a wide geographic coverage, and focus on a specific set of stressors to illustrate different management scenarios.

7.2. Applications of Research

“Applied sciences do not exist. Only applications of science" (J.L. Pasteur)

These were researches finalized to having practical outcomes. However, they are endowed with advanced techniques and tools.

[i1] 1994-1997 - Hydrological model of the River Adige for the prevention of floods. Currently operational at the Autorità di bacino (the River Adige Basin Authority).

[i2] 2000 Plan for the sustainable development of Trento : characterization of water resources and characterization of carbon dioxide emissions.

[i3] 1999-2001 Estimation of the annual hydrological cycle of Lake Serraia

[i4] 2000-2001 - Real time modelling of floods of the River Adige (Civil Defence of the Province of Trento)

[i5] 2003, The morphometry of the main river basins in Trentino (PGUAP).

[i6] 2005, Document for the Province of Trento Law on Hazard Mapping, co-authored with a panel of experts and stake-holders.

[i7] 2005 -Hydrological study of the Argentina river (IM, Italy).

[i8] 2005 - Hazard mapping of Rio Velt and Kortol areas, Sauris (UD, Italy). Finaced by the Sauris Municipality.

[i9] 2005 -2006 - New version of the real time model of the River Adige (the snow evolution and ablation component)

[i10] 2006-2008 - AUTORITA’ DI BACINO DEL FIUME ADIGE (River Adige Basin Authority), A new hydrological model of the River Adige for the prevention of summer droughts.

[i11] 2009-2011 - Hazard Mapping. Servizio Bacini Montani P.A.T. (Mountain Catchments Service of the Autonomous Province of Trento). The project aimed to define the guidelines for mapping hydrogeological hazards in the Province of Trento.

8. Spin-offs

Over the last ten years, Rigon, as required by the modern mission of Universities and by his own concern about the future of his more brilliant students, contributed to the birth and life of two small companies, to which he provided part of the know-how, and the necessary encouragement and advice.

8.1. Hydrologis

HydroloGIS Srl is an Environmental Engineering company whose aim is to support environmental engineering through the development and the application of environmental models that make use of the best available IT. HydroloGIS was estabilishd in 2005 by its two partners Ing. Ph.D. Andrea Antonello and Ing. Silvia Franceschi, both of whom have gained several years of experienced in research projects at the Department of Engineering of the University of Trento, especially under Rigon's guidance. Since its establishment, Hydrologis has been based at TIS innovation park of Bolzano, where it was accepted after a comprehensive screening of its business plan. HydroloGIS specialises in the development and modelling within GIS frameworks, starting with the models that were conjointly developed with Rigon. The collaboration with Rigon and CUDAM gave rise to the release of JGrass, the Horton Machine (a set of tools for terrain analysis), and the first version of the model JGrass-NewAGE, which was sponsored by the Adige River basin authority,

All models developed by HydroloGIS are integrated into GIS JGrass, a project which HydroloGIS coordinates on a world-wide level. JGrass is programmed in Java and released under LGPL license. Now JGrass is part of the uDig project.

Over the years, Hydrologis eventually emancipated itself from its "Alma Mater" and started collaboration with other Universities and Institutions worldwide, still maintaining ongoing collaborations with Trento University. Among the recent developments are GIS tools for tablet PC for field surveys (produced by a collaboration of Hydrologis with University of Urbino) and GIS tools for Android devices, called Geopaparazzi, adopted internationally. At 2014 the company celebrated ten years and is completely autonomous.

8.2. Mountain-eering/MobyGIS

Mountain-eering Srl, a portmanteau for Mountain Engineering, was born in 2008 as a Consultancy Engineering Company on environmental topics founded by three former students of Rigon, Ing. Ph.D Matteo Dall'Amico, Ing. Ph.D. Silvia Simoni and Ing. Fabrizio Zanotti. Rigon had also a small participation in the company (%1), as required by Trento University regulations,until 2014 when the spin-off phase finished.

Mountain-eering Srl is the first Spin-off of the University of Trento and is a Start-Up of the TIS (Technology Innovation Sudtirol) of Bolzano. The company has its headquarters in Bolzano (Italy) at TIS and a satellite office in Trento (Italy).

Mountain-eering provides services in the following sectors:

analysis of natural hazards, finalized to the prevision/ mitigation of hazards and to the defense of vulnerable infrastructures;

hydrological analysis of mountain environments (e.g. rivers, glaciers, high mountain), finalized to the quantification of the water resources and identification of possible future scenarios;

environmental measures (topographical surveys finalized to the measurements of rivers and mitigation structures and water measures in rivers and soil).

Among the tools used for the investigations, Mountain-eering uses and develops, conjointly with the University of Trento, the GEOtop model, whose code is actually distributed from a repository of the company. In more recent years, Mountain-eering has opened collaborations with the University of Lausanne in Switzerland, and other institutions. During the first three years of activity Mountain-eering doubled its turnover each year. In 2014, after five years of incubation, Mountain-eering is a young active company that employs a total six people. Now a new company MobyGIS, more focused on GEOtop, sprout from Mountain-eering and maintains the collaboration.

9. Details of the Research Activity

The following paragraphs comment Rigon's recent scientific work, with citations [in square brackets]. It will be clear that the work pursued by Rigon follows coherent routes and shows continued progress. Research topics are presented from the more recent to the older and more consolidated.

9.1. Study of cryospheric hydrology

In [j22] it was demonstrated that a single-layer snowpack model can be sufficiently accurate in describing the evolution of the water equivalent of the snow, as long as the incident radiation is calculated accurately taking care of shadows and the complexity of mountain topography. Subsequently, during the thesis of Stefano Endrizzi, the single-layer model was replaced with a multilayer one in order to forecast the evolution of density and the metamorphism of the snow as well as percolation within the snowpack itself. Among the various studies carried out, one validates the snow model satellite data derived from MODIS [a41]. Furthermore, the same model was used to study the hydrological evolution of glaciers in Trentino (Alpine) and South America (Equatorial) [a39,a47]. Eventually, the modeling of the cryosphere moved towards considering evolutive processes of permafrost [thesis of Matteo Dall'Amico, and j30], that is the layer of soil subject to temperatures below zero °C for more than two consecutive years. All of these research projects, as well as allowing the aforementioned studies, are necessary to modeling the entire yearly hydrological cycle in mountain environments such as Trentino.

[j30], drawing from an accurate work of reanalysis of process thermodynamics, implements a robust method for the integration of the freezing-soil equation. The numeric algorithm used is globally convergent Newtonian method that is appropriate for the equations under study. [j36] is a geomorphological survey of rock glaciers in Trentino, to be subsequently modelled with GEOtop.

9.2. Physico-statistical modelling of the Water Cycle at basin scale

While GEOtop [j24,j25] is for process-based modelling of the mass and energy budgets at a small scale, in order to model larger catchments, which include abstraction works or hydraulic structures, it was decided to implement a new modelling system JGrass-NewAGE [j34]. This system sacrifices process detail in favour of efficient calculations. It is made of components apt at returning statistical hydrological quantities, opportunely averaged in time and space. One of the goals of this implementation effort was to create the basis for a physico-statistical hydrology in which the hydrological spatially distributed dynamics is reduced into low dimensional components, when necessary surrogating the internal heterogeneities with "suitable noise" and a probabilistic description. Unlike other efforts of synthesis, JGrass-NewAge wants to keep the spatial description explicit, at various degrees of simplicity. This has

been made possible by opportune processing of distributed information which, in this way, has become part of the model itself. From the point of view of the information technology used to implement the modelling [j40,a45,a49,a50], the system is based on the OMS v 3 system, which allows the use of modern, object-oriented strategies for the structuring of the deployment of the software and, at the same time, furnishing not a model, but various, interchangeable, modeling solutions (MS) that can be adapted to the problems in hand and the practical demands of the problem being solved. The modeling system, as well as the components to model the physical processes themselves, also includes various tools for the processing of input data (for example, Kriging tools in [J59]), including all the tools of the Horton Machine [eb3] for the processing of digital terrain data, and the tools for the treatment and interpretation of the output data, for the calibration of model parameters, and (in perspective) for continuous data assimilation. With this in mind, an effort that is currently being made is that of creating an opportune digital watershed scheme that can accommodate the needs of the various modeling conceptualizations and the identification of areas that are hydrologically "similar" that can be treated conjointly during the calculation of flows and storage. At the moment, model solutions use standard implementations. [j34, j41, a50] contain the description of the rainfall-runoff part of the modelling system; [j39,j54] are a verification of the radiation budgets components; [j42] is an example of simplified snow modelling. As a standard, any component is verified by itself against the data relative to the process that it describes, using various automatic calibration procedures, and quantitative objective functions. [j34, j41], using the infrastructure, show how increased geomorphological (and processes) information affects the quality of reproduction of the hydrologic response. [j44] explains the watershed partition, based on a generalisation of the Pfafstetter numbering scheme, that guide the functioning of the JGrass-NewAGE system. Abera's work [j52,j55 and j56] streamlines the procedure to estimate the water budget of a small pre-alpine basin and the blue Nile, at a large scale. Various and different techniques are used in the two cases to get the information required to give proper hydrological answers. In the first case, especially ground measures are utilised, in the second case mostly satellite measures whose bias is determined by ground measures. All of these models are systems of ordinary differential equations (ODEs), i.e. dynamical systems. [J53] shows how, given the set of equations, travel time distribution and residence time of water in hydrological cycle compartments are given. The topic is further expanded in [j60 and [j61] on the ground of a new graphical representation of models and some new (for hydrology) mathematics.

9.3. Study of landslide and mass flow triggering

The role of hydrology in triggering mass movements was initially confronted with an implementation of the theories of Montgomery and Dietrich [1994], which even generalized the case of instability caused by surface runoff [a21,a21,a26, a27]. The study then continued with the analysis of transient phenomena, that is the instabilities caused by the propagation of pressure waves in the unsaturated medium [a33, a34], even in the case of rainfall of varying intensity [a21, j23]. Then, the simplified approach proposed by Iverson [2000] (important in as much as it highlighted some qualitative aspects of infiltration in the hillslopes) was supplanted by the use of the GEOtop model for the continual simulation of hydrological variables [a38, j26]. The use of GEOtop

has allowed for the separation of the hydrological part, effectively modeled by GEOtop, and the geotechnical part, contained in the GEOtop-FS model. Particularly, the latter of these was the subject of a probabilistic treatment that introduced uncertainties into the main geotechnical parameters [j26]. This paper, [j26], and the thesis of Silvia Simoni introduced a systematic approach to the identification of areas of instability that made full use of the potential of on-site geophysical measurement campaigns and the a priori characterization of geotechnical properties of the soil in the laboratory, without using back analyses for the calibration of parameters as is generally done by simplified models. The IRASMOS Reports [rep06, rep07 and rep08] represent a summary of the literature available on this subject which has been eventually refined in [rep09].

The most recent work [a43] has been focused on trying to understand the dynamics of subsurface flow in conceptualised terms and by means of virtual experiments, and to explicit the role of the variability of depth of soil [j33,j35,j37]. The result is the introduction of the concept of "hydrological connectivity" of the hillslopes, which is realized when a perched water table forms that covers the whole basin. The connectivity concept bridged the gap between hillslope hydrology and basin hydrology, and also has important consequences for hillslope stability [j37]. In fact, the basis of these concepts, allows a better statistical identification of landslide areas. [j35] also contains a preliminary attempt to use the theories of self-organizing criticalities in the context of instability propagation, which evidently heralds the actual landslide itself.

Paper [J46] faces the issues related to the choice of a certain parameterisation of the soil retention curves and analyses their relation to hillslope stability. It uses a new theory that uses double porosity, and estimates the stability with the use of the new theories by Lu, Likos and Godt. [j49], on the basis of these theories, investigates the effects of topography on stability putting a quantitative justification that convex area are more prone to landsliding than concave ones. Rigon recently abandoned these studies to dedicate more attention to the generalisation of Richards equation (as explained in the part dedicated to process-based modelling).

9.4. Hydroinformatics, GIS and modeling by components

Research in the aforementioned sectors was also carried out with the implementation of open-source software, coded in C and Java and distributed with a GPL (v 3) license. Involvement in this topic has been deemed necessary to facilitate cooperative research and to improve reuse of codes and incremental development of modelling solutions. The software has been accurately documented [eb1 to eb13] so that it can be easily reused and modified for both research and didactic purposes. The software originally included a series of C libraries for reading, writing and insertion of comments in the data files, dynamic allocation of memory, the statistical treatment of data aimed especially at hydrology, hydraulics, and geomorphology, but not limited to these. On the basis of these libraries, the initial version GEOtop model [j24, s3] and an initial version of the *Horton machine* [e.g. eb-3, s3] were implemented. However, the traditional architecture presented various limitations: the lack of an interface for the processing of input data and the treatment of output data; the difficulty of maintaining and testing the software and its components in an independent way, given the growing number of processes being described [e43]. Further, it became necessary to be able

to test and use some parts of the model separately (as in JGrass-NewAGE) and to be able to link it (in the future) to external models, such as, for example, models describing the evolution of the atmospheric boundary layer. Over a decade of work, these and other reasons, have brought, on the one hand, to the development of a new GIS, JGrass, eventually embedded in gvSIG, and, on the other, to the adoption of suitable informatics infrastructure in order to restructure the models in components according to the OMS v3 standard.

In the some version, JGrass has partially contributed to the uDig "core" [eb10, A49, J41], while the modeling part is migrating to the jgrasstools environment (based on OMS) called Spatial Toolbox. The Iversion of the tools has been embedded in Hydrologis' S.T.A.G.E. which is a stand-alone application connectable, in principle, to any Java GIS (thinking towards future versions of uDig or gvSig). Eventually the jgrasstools environment, renamed "Horton Machine" was brought to gvSIG, and, as a stand-alone to the GEOframe infrastructure.

Over the years, various prototypes where developed around the above infrastructures to connect models to SQL/Geographic databases (Postgresql/Postgis), to visualise results on the Nasa World Wind virtual globe, and to allow scripting to interact with models which were presented in various conferences, and on which we could discuss with those interested.

Recently the OMS infrastructure has been renewed [a60,a63] to include a graph structure called Net3. It, initially designed on the metaphor of river networks connecting hydrologic response units, has been expanded to describe any set of models connected by inputs and outputs and forming a direct acyclic graph. Each node is a model set, any edge represent an input or an output. The graphs commands the execution of the submodels and they are executed in parallel, if the topology allows it. This allows to researchers in hydrology to concentrate more on their own task and avoiding the complexities to cope with parallel programming.

The same OMS infrastructure has also been expanded to make room to the possibility to manage surrogate models. i.e. models built on artificial neural networks that learn on physical based models and simplify users experience in managing forecasting of the hydrological cycle.

9.5. Process based physical modelling of the water cycle

The first studies in this field took inspiration from analyses of moisture distribution in the soil, [j14, a8], where it was shown that during relatively "dry" periods the moisture distribution in the soil can be understood and described with fractal analysis techniques. From these studies, and the desire to model evapotranspiration, eco-hydrological phenomena, hydrology and slope stability, and the evolution of the snowpack, there arose a need to develop an instrument capable of modelling the water cycle and soil moisture dynamics continually over time. These goals were the founding reasons for the implementation of the GEOtop Model [j24, a22]. GEOtop is "terrain-based" (it is based on the use of digital terrain models and uses the knowledge of interactions between morphology and process), "distributed" (all the simulated variables are calculated for each pixel of the basin) model of "the water cycle" (it simulates all the

components of the water cycle, taking account of both the mass budget and the energy budget, the two budget equations being coupled through the temperature of the soil, which controls evaporation, hydraulic conductivity, and accumulation of the snowpack [j22]). A complete description of the model can be found in [j24, a22], articles that present the model system and a practical application to the Little Washita basin in Oklahoma, and, obviously in the user manual [eb05].

The GEOtop model was also applied during the study of the water cycle of Lake Serraia (Trentino, Italy) [a34]. [j25] demonstrates the effects of complex topography and morphology on the water cycle. In particular, one can observe that a more extensive channel network (as might arise in presence of greater slopes or more erodible soil) causes greater surface runoff and less evapotranspiration, which in the energy budget causes an increase in latent heat exchange with atmospheric boundary layer. The paper demonstrates, therefore, that topographic effects cannot be neglected in formulating the energy budget of the soil, as most global climate models normally do. Among the more theoretical studies, but essential to the distributed modelling of flows in unsaturated media, are [j27,a29]. In [j27] the Richards Equation was perturbatively decomposed into a vertical component and a lateral one. The first dominates the initial phases of infiltration, the second the long-term redistribution of water volumes. With the work reported in [j30] the model was expanded with a soil freezing and thawing module, that allowed the analyses of the PERMANET project to be executed, and other studies performed by other researchers.

Recently, the GEOtop model has been used to estimate the impact of climate change on river discharges [rep02]. Ancillary studies have been dedicated to parameter calibration and uncertainties in hydrologic model forecasting [a37, a40].

A small community of users and developers has developed around GEOtop, which is steadily growing as documented at http://www.geotop.org.

The article [j38] envisages the restructuring of the GEOtop model with new numeric methods, developed together with Prof. Vincenzo Casulli, and the adoption of a non-structured grid for the modelling. [J43] represents the state-of art of GEOtop version 2.0, a milestone in the model history which contains Richards 3D integration, permafrost modelling, a multilayer snow model, renewed options for the treatment of meteo-data and radiation. [J44] embraces the use of the CLM model, and faces the problem of data assimilation complemented by the use of Kriging techniques for filling the missing data.

At present, the development of GEOtop (version 3.0) has been taken over by the GEOtop association which is providing a refactoring of the codes, their continuous integration, code parallelization and various tools for supporting applications. Rigon with its Ph.D. students is instead evolving a new version (4.0) based on OMS v3 and new algorithms for Richards equation integration (including freezing soil) and snow modelling. Synergistically, a theoretical and coding effort is ongoing to provide new representations of evaporation and transpiration phenomena.

9.6. Hydrogeomorphology

The work on the evolution of river networks certainly enters in this category. Here, however, those papers that deal directly with quantitative geomorphological analysis are presented. In most of the papers, the relationships between the various parts of a river basin are analyzed with fractal geometry techniques. Such knowledge is useful not only for the evaluation of river basin evolution models, but also in identifying the nature of their hydrological response to given events and their paleoclimate. In [j2], using the Peano Basin, a mathematical reference structure, it is suggested that the amplitude function of natural networks can be reproduced with a multifractal multiplicative process. In [j11] this concept was rigorously formalized in the framework of random multifractal cascades theory. In [a6], an initial analysis of the possible impact of climate on the form of a river network was carried out. The fractal properties, that is power laws relating to contributing areas and the length of stream reaches, were rigorously formalized in [j15]. In [j17] more relationships between these characteristic quantities were found and an explanation of the nature of Hack's Law is suggested. The relationships were verified experimentally by means of remotely sensed data. In [j27] the structure of the river networks is further investigated by analysing tributary statistics. Given programmes for the extraction of digital terrain models (DEM) and their treatment, the natural development was the implementation of an open-source geographic information system: JGrass [www.jgrass.org], [s2]. JGrass contains within the package a large amount of georeferenced territorial analysis methods, jointly known as the Horton Machine [eb-3], to support the most common, and some of the less common, tools for the analysis of river networks topology, channel extraction, hillslope delineation. A review of these tools is in [a57].

9.7. Modeling the evolution of channel networks

Chronologically, one of Rigon's first interests was modeling the evolution of channel networks according to principles of minimal energy dissipation and self-organization by critical states. These two types of models proved to be capable of reproducing the two- and three-dimensional statistical characteristics of channel networks and natural basins, as well as the fractal and multifractal characteristics. This work, born with the intent of identifying a minimum set of characteristic dynamic elements in the evolution a hydrographic basin, has always been carried out in parallel to the refinement of measurement and analysis techniques of topographic data [j3].

The concept of optimality of a hydrographic basin was introduced in [j3, j4, j5]. In these works, the three postulates of optimal channel networks (OCN) are stated and developed, proving how such principles can have quantitative effects on the morphology of river networks, particularly affecting the structure of slopes and of contributing areas, the geometry of the channels, and the characteristic velocity of the peak flow of a basin. All of these results explain numerous empirical laws and are still the basis of measurement campaigns.

In [j4], that which was postulated in [j3, j5] was verified by numeric simulation. It should be noted that the minimization of dissipated energy generates fractal forms that reproduce the quantitative characteristics of real basins. In [j6] the concept of

optimality is further refined by introducing the hillslope contribution and presenting some case studies. In [j6], more tools are introduced for the qualitative comparison between the numeric models and the natural data. In [j8, j9, a6] a model of the evolution of river basins is presented that is based on the concepts of self-organization by critical states. This model proved to be equivalent to the optimization model of [j3-j6]. In [j13] the impact of climatic variability on the morphology of the fluvial landscape is simulated, so offering an interpretative framework for some fluvial forms that can be found in nature.

Subsequently, the concept of optimality was refined observing that real basins do not have the configuration that would give an absolute minimum of dissipated energy, but rather that of states of local minimum that are dynamically accessible. From here the concept of feasible optimality was derived [a10, j18, j19]. It was also demonstrated that the states of absolute minimum, dynamically unreachable, have statistical properties that are not realistic, while accessible minimum states have the desired statistical characteristics. A relevant characteristic of the space-time dynamics of hydrographic networks is that they can be described by means of a parameter that can be linked to temperature [j16]. It is therefore possible to define the "thermodynamics" of the river networks. As with the thermodynamics of other physical systems, the relevant quantities are energy (dissipated in unit time), entropy, and the temperature.

It should be noted that the space-time evolution of river networks happens with an intermittent behaviour similar to the concept of "point equilibrium" proposed for the evolution of biological species. It was also demonstrated that the temporal dynamics of river networks is coupled with the spatial activity at all scales and that natural networks, therefore, evolve according to conditions of minimum dissipation of energy but in the presence of a great variety of possible dynamic states.

In [j10] an accurate analysis of the fractal and multifractal properties of optimal river networks was carried out. The note [j18] is a review article, sent to the Annual Review of Earth and Planetary Sciences, that treats the aforementioned topics. [j20] presents the results of a theorem on network topology that relates the sum of the contributing areas with the contributing areas themselves and hypothesizes that these quantities are analogous to the ratio of metabolic rhythm and mass of living beings. The two quantities are linked by an exponential law with an exponent that was proved to be Hack's exponent.

This work, born with the intent of identifying a minimum set of characteristic dynamic elements in the evolution of a hydrographic basin, has always been carried out in parallel to the refinement of measurement and analysis techniques of topographic data [s2,eb3]. Recently, this field of study has produced a work [j26] where the morphometric statistics of tributaries of natural rivers and OCNs are studied. These are related to the characteristics of peak flows and they have ecological implications such as, for example, the velocity of diffusion of waterborne diseases and the diffusion of species along the river network. In Rigon's work, the morphological relations between the different parts of fluvial basins have been analyzed with ever more refined numeric instruments, to the point of creating a series of GIS methods known as the Horton Machine [eb3].

The paper [J41] is partially a review of old results, that were not collected before, and were overlooked by people because they did not appear in Rodriguez-Iturbe's

and Rinaldo's 1997 book. It includes, however, some new sets of simulations where injection of rainfall is assigned with certain distributions (with a given correlation structure) producing differentiated power laws for discharge and contributing areas: clearly a result requiring further exploration.

9.8. Rainfall-Runoff (Peak Flows) Modelling

These works show that the detailed knowledge of a river basin's morphology allows one to frame the main features of the hydrological response in terms of a minimal set of dynamical parameters. This is relevant insomuch as the form of river networks can now be measured with automatic and objective remote-sensing techniques. Typically, the required dynamical parameters are the mean flow velocity in the network and distribution of residence times of water in the hillslopes. In this context, the variance of the GIUH is proven to depend mostly on the structure of the pathways followed by the single volumes of effective rainfall from their release points to the control cross-section (geomorphological dispersion), [j1], rather than on the hydrodynamic dispersion; the latter becoming relevant only at the large scale. Generally, it is possible to determine with precision the first moment, the variance, the skewness, and the kurtosis of the hydrological response of a river basin as a whole [a3, a9]. In [a7] the production mechanisms of effective rainfall and the characteristic contributions of the hillslopes are studied. As a result it was observed that rarely is the response time of the hillslopes negligible when calculating the hydrological response of the river basin as a whole. In [a18,a19, j21] the use of amplitude functions in the construction of the GIUH and the concept of including information about initial moisture conditions for the basis are further developed. In this way it was observed that, with varying fractions of saturated river basin, the hillslopes and channels contributed different fractions to the flood wave; the hillslopes being particularly important under conditions of extreme saturation of the basin [j21]. The formulation of the GIUH on the basis of amplitude functions has also given semi-analytical results regarding peak times and maximum discharges for a basin [j31].

Subsequently, the study of the hydrological response was directed mainly towards the investigation of runoff production mechanisms on hillslopes, in relation to the soil depth [j33,j35,j37].

Eventually, the study of the hydrological response was directed mainly towards the investigation of runoff production mechanisms on hillslopes (actually in researches related to hillslope stability), in relation to the soil depth [J33, J35, J37] and brought new insights to the concept of hydrological connectivity. These studies overcome the results in [A29] that, while interesting, assume simplistic hillslope setups. Parallel efforts were made in overcoming the limitations of event-based modelling, as reported in previous sections.

The paper [j47] is a review taken from a historical-critical point of view of the theory of the geomorphological unit hydrograph that also broadens the view to the modern theories for describing water fluxes by travel time. It also serves as the starting point for future research in this directions. [j53] builds on new findings by Botter and coworkers and bridges hydrological dynamical systems and travel times quantities. It also had budget [j60] and [j61] which constitute part of a reflection on the nature of hydrological dynamical system and their relation with similar systems that deal over other topics like brain research, studies on networks, theoretical biology, reaction networks.

9.9. Contributions on occasional topics

During is research activity, Rigon has always been careful that the process might have didactic and practical consequences. [d1] summarizes a series of lectures given about the mathematical modeling of physical processes. [d2] is the collection of slides of Rigon's lectures on hydrology. Following an increased interest in mini-hydroelectric plants, Rigon has characterized the flow from a a bottom-grill using modern experimental techniques [a41]. In [a16], by means of geomorphological techniques, he investigated the possibility of shortcut estimating the order of magnitude of the maximum sediment flows in mountain basins. [j32] deals with the discovery of pseudotachilites (i.e. rocks that are fossil witnesses of an earthquake) in sedimentary formations and, obviously, the statement is justified on the basis of chemical, spectrographic, and petrographic analyses.