

geotopbricks: An R Package for the Distributed Hydrology

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github.com/ecor

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github.com/Ecohydro



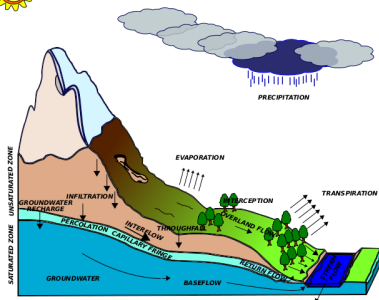
Who are we?



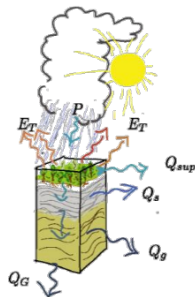
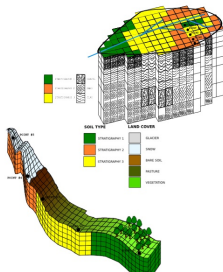
- ▶ Environmental engineers with hydraulic and hydrological background (more deterministic and physical-based than statics!)
- ▶ Some of us are researcher, other are self-employed and freelancers - www.rendena100.eu .
- ▶ Some of us are author of several R-packages and R enthusiast.
- ▶ Some of us are developers of GEOTop hydrologic models with skills in hydrology and environmental science and also in C/C++, parallel programming, High Performance Computing, etc

Hydrology

Scientific study of the movement, distribution, and quality of water on Earth water cycle, water resources and environmental watershed sustainability [Wikipedia]



Hydrological models



Soil water mass balance equation:

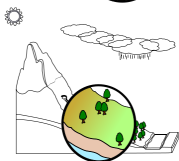
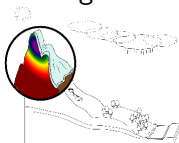
$$\frac{\partial \theta}{\partial t} = \nabla \cdot [K (\nabla(\psi + z_f))] + S + \dots$$

Soil Heat (energy) balance equation:

$$C_s \frac{\partial T_s}{\partial t} = \nabla \cdot [K_t (\nabla T_s)] + \lambda S + \dots$$

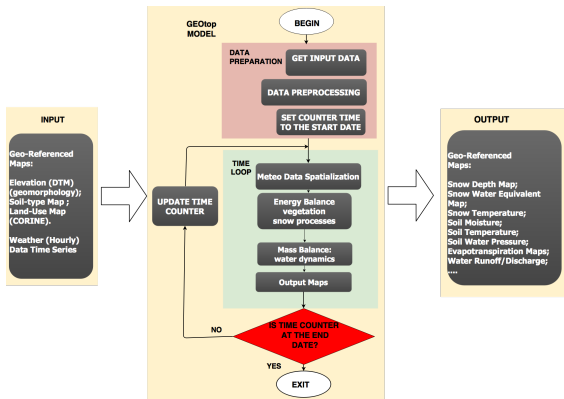
GEOtop Hydrological Model

GEOtop is an open-source integrated hydrological model, available through Github, www.geotop.org, simulating:



- ▶ soil water flow in the soil (*Richards' equation, De Saint-Venant Equation*);
- ▶ heat flow in the soil → (*heat equation and frozen soil thermodynamics*) ;
- ▶ energy exchange with the atmosphere → boundary conditions of the equations above.

GEOtop Hydrological Model Structure

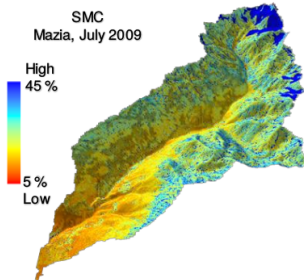
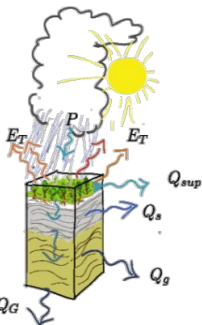


- **Input:** meteo data, elevations, soil parameters, . . .
- **Output:** snow cover, soil temperature, soil moisture, . . .

GEOtop Hydrological Model Options

Water and/or energy budgets can be activated (both or only one) by users in function of the specific use case. GEOtop has two setup configurations :

- ▶ **1D:** only vertical fluxes → mass and energy balance at local scale (only in one soil column)
- ▶ **3D:** vertical and lateral fluxes → balances at basin scale



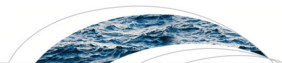
GEOtop Hydrological Model Software Package / Source Code

Core components of GEOtop software packages are:

- ▶ written in C/C++
- ▶ released in 2014 (version 2.0) as free open-source project, a re-engineering process is going to finish (version 3.0);
- ▶ scientifically tested and published;

Source code and documentation are available on GitHub repository: [<http://geotopmodel.github.io/geotop/>].

 **AGU**PUBLICATIONS



Water Resources Research







RESEARCH ARTICLE

10.1002/2016WR019191

Key Points:

- Seven hydrologic models were intercompared using three benchmarks of increasing complexity
- Models showed good agreement with respect to various hydrologic responses (storage, discharge, and

The integrated hydrologic model intercomparison project, IH-MIP2: A second set of benchmark results to diagnose integrated hydrology and feedbacks

Stefan Kollet ^{1,2}, Mauro Sulis ³, Reed M. Maxwell⁴, Claudio Paniconi ⁵, Mario Putti⁶, Giacomo Bertoldi ⁷, Ethan T. Coon ⁸, Emanuele Cordano^{7,9}, Stefano Endrizzi¹⁰, Evgeny Kikinzon⁸, Toulouse, France
Emmanuel Mouche¹¹, Claude Muegler ¹¹, Young-Jin Park¹², Jens C. Refsgaard¹³, Simon Stisen¹³, and Edward Sudicky^{14,15}

geotopbrick R package: Why?

- ▶ complexity in input/output/configuration files (“frontend”) and data difficult to handle
- ▶ need of user friendly environment for to GEOTop data tidying and data analytics (e.g. *R*)

```
113 -----
114 ! LAND COVER
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116
117 Urban1, Pasture 2, Grassland 3, Agricultural 4, Broad leaf forest 5,
118 Bare Rocks 6, Bare Soils 9, Glacier 10, Lake/Marsh 11
119
120 NumLandCoverTypes = 11
121 SoilRoughness = 1,10,10,10,10,10,10,10,1,1
122 ThreeSnowSoilRough = 10,10,10,10,10,10,10,10,10
123 VegHeight = 0,200,600,600,1800,1800,1800,0,0,0
124 ThreeSnowVegUp = 50,50,50,50,50,50,50,50,50
125 ThreeSnowVegDown = 10,10,10,10,10,10,10,10,10
126 LAH = 0,2,5,7,7,0,0,0,0
127 CanopyReaction = 0,0,7,1,1,1,1,1,0,0,0
128 DecayCoeffCanopy = 2,5,2,5,2,5,2,5,2,5,2,5,2,5,2,5
129 VegSnowBurying = 1,1,1,1,1,1,1,1,1,1
130 RootDepth = 0,200,300,500,700,700,700,0,0,0,0
131 MinSnowmeltRes = 60,60,60,60,60,60,60,60,60,60
132 VegReflectVis = 0,1,0,1,0,1,0,1,0,1,0,1,0,1,0,1
133 VegRefInIR = 0,58,0,58,0,58,0,58,0,58,0,58,0,58,0,58
134 VegTransVis = 0,05,0,05,0,05,0,05,0,05,0,05,0,05,0,05
135 VegTransIR = 0,25,0,25,0,25,0,25,0,25,0,25,0,25,0,25
136 LeafAngles = 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
137 CanDensSurface = 0,5,0,5,0,5,0,5,0,5,0,5,0,5,0,5
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140 SoilAlbWet = 0,15,0,15,0,15,0,15,0,15,0,15,0,15,0,15
141 SoilAlbIRWet = 0,25,0,25,0,25,0,25,0,25,0,25,0,25,0,25
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```

GEOtop configuration File (geotop.inpts)

A GEOtop simulation is organized in a set of files within a directory containing a **configuration file**, called *geotop.inpts* filled with a keywords system addressing to:

- ▶ simulation

options

(e.g. simulation
period)

InitDateDDMMYYYYhhmm=09/04/2014 18:00

EndDateDDMMYYYYhhmm =01/01/2016 00:00

- ▶ **input files**

(e.g. meteorological time
series)

[...]

MeteoFile = "meteoB2_irr"

PointOutputFile = "tabs/point"

- ▶ **output files**

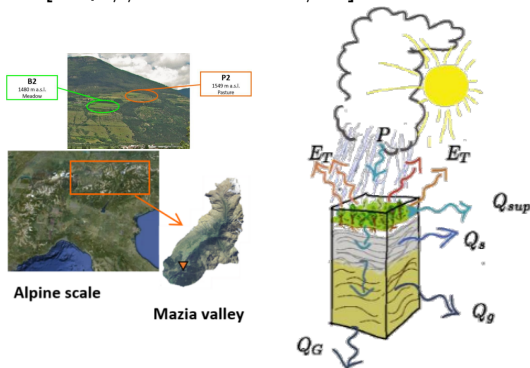
geotopbricks Technical details

The aim of **geotopbricks** , starting in 2013, is to bring all the data of a GEOtop simulanon into the powerful statistical **R** environment by using the keyword-value syntax of *geotop.inpts*. **geotopbricks** does the following actions:

- ▶ to parse *geotop.inpts* configuration files;
- ▶ to derive from *geotop.inpts*'s keywords the source files of I/O data;
- ▶ to import time series (e.g. precipitation, temperature, soil water content, snow) as *zoo* or *data.frame* objects;
- ▶ to import spatially and spatio-temporal gridded objects as *RasterLayer-class* or *RasterBrick-class* objects (**raster** package)

1D Simulation of soil water budget in an alpine site: two points

Soil water content (SWC) in two points P2 and B2 located in Val Mazia/Match, Malles Venosta/Mals Vinschgau, South Tyrol, Italy [<http://lter.eurac.edu/en>].



B2



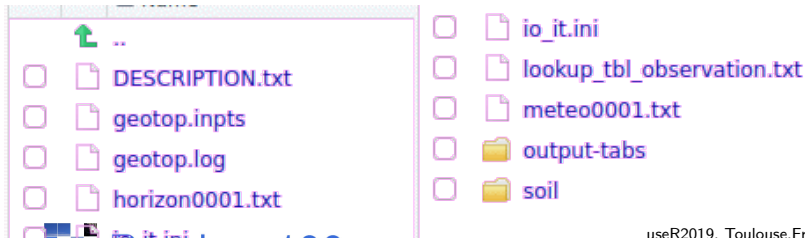
Simulation of soil water budget in an alpine site

Here is the directory containing files of B2 point simulation:

```
library(geotopbricks)
```

```
## SET GEOTOP WORKING DIRECTORY
```

```
wpath_B2 <- "resources/simulation/Matsch_B2_Ref_007"
```



Getting simulation input data

Meteorological variable time series are imported and saved as 'meteo' variable (class 'zoo'). This variable is retrieved through the GEOTop keyword **MeteoFile** :

```
tz <- "Etc/GMT-1"
meteo <- get.geotop.inpts.keyword.value(
  "MeteoFile",
  wpath=wpath_B2,
  data.frame=TRUE,
  tz=tz)
class(meteo)
```

```
## [1] "zoo"
```

Getting simulation input data (verify)

Meteorological time series once imported are available in the R environment:

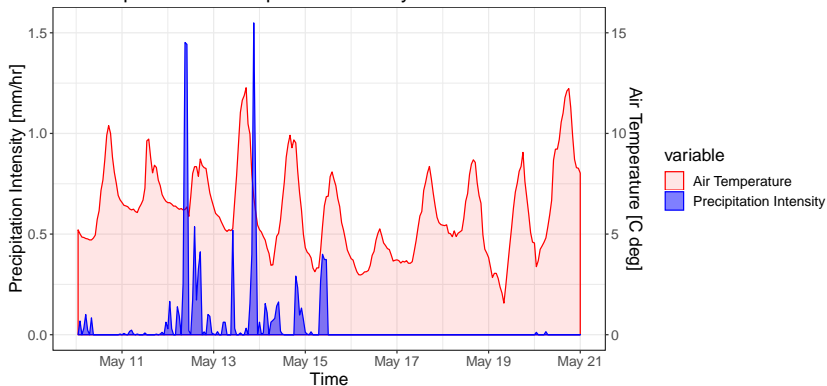
```
head(meteo[12:14,c("Iprec","AirT","Swglobal")])
```

##		Iprec	AirT	Swglobal
##	2009-10-02 11:00:00	0	12.38	396.02
##	2009-10-02 12:00:00	0	13.12	500.07
##	2009-10-02 13:00:00	0	13.96	564.02

```
head(meteo[12:14,c("RelHum","WindSp","WindDir")])
```

Plots of weather variables in B2

Air Temperature / Precipitation Intensity vs Time at B2



Getting results of the simulation at B2

Soil Water Content Profile:

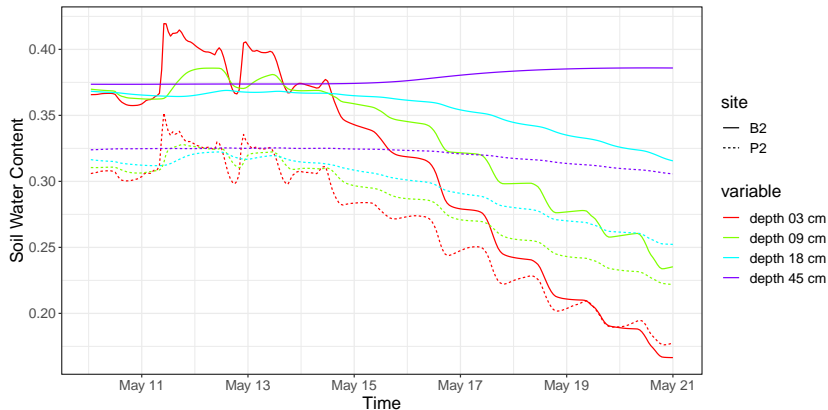
```
tz <- "Etc/GMT-1"
SWC_B2 <- get.geotop.inpts.keyword.value(
  "SoilLiqContentProfileFile",
  wpath = wpath_B2,
  data.frame = TRUE,
  date_field = "Date12.DDMMYYYYhhmm.",
  tz = tz,
  zlayer.formatter = "z%04d"
)
help(get.geotop.inpts.keyword.value) ## for more details!
```

Getting results of the simulation at B2

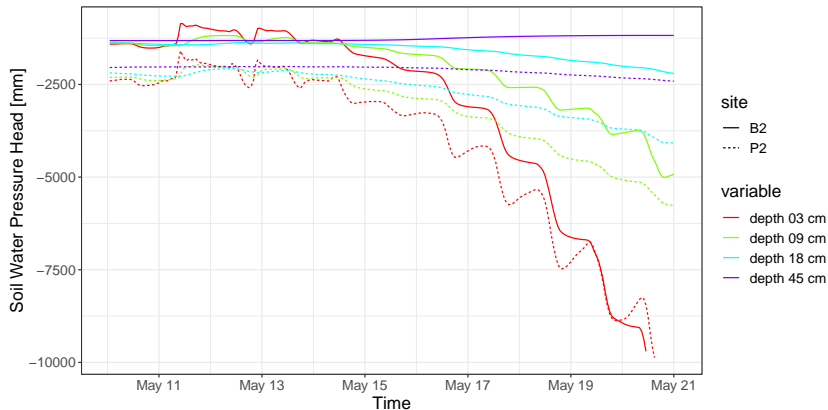
The same for P2:

```
wpath_P2 <- "resources/simulation/Matsch_P2_Ref_007"  
SWC_P2  <- get.geotop.inpts.keyword.value(  
  "SoilLiqContentProfileFile",  
  wpath = wpath_P2,  
  data.frame = TRUE,  
  date_field = "Date12.DDMMYYYYhhmm.",  
  tz = "Etc/GMT-1",  
  zlayer.formatter = "z%04d")
```

Soil Water Content at P2 and B2

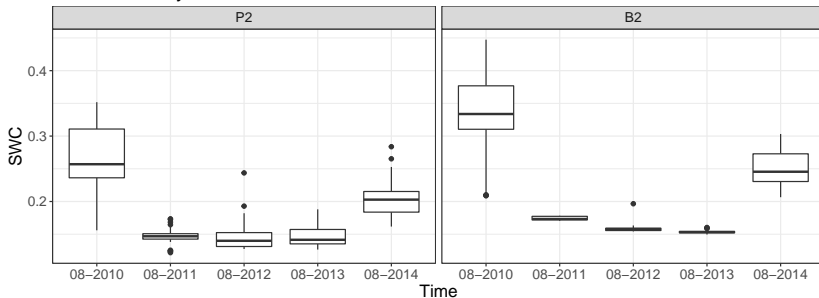


Soil Water Pressure Head at P2 and B2



Example of an Output Data Analytics (Soil Moisture Distribution)

Distribution of daily aggregated soil water content at a 18 cm depth:
Box Plot: Daily Soil Water Content



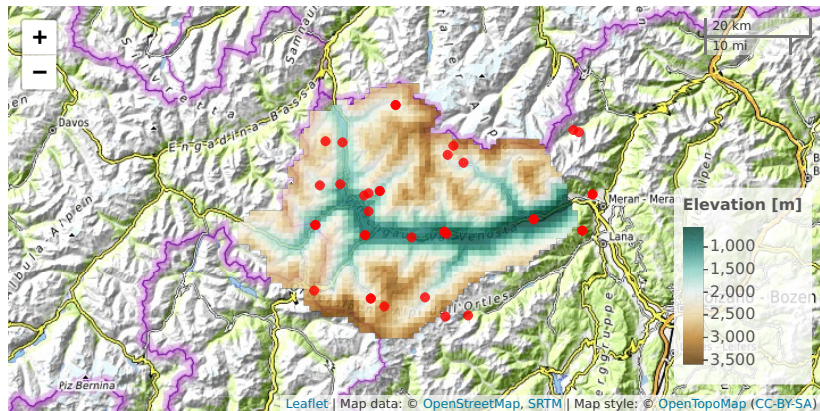
More details on the **eRun2018** poster.

3D Spatially Distributed Distribution: Val Venosta/Vinschgau - Upper Adige River Basin - Alps - I/CH/A

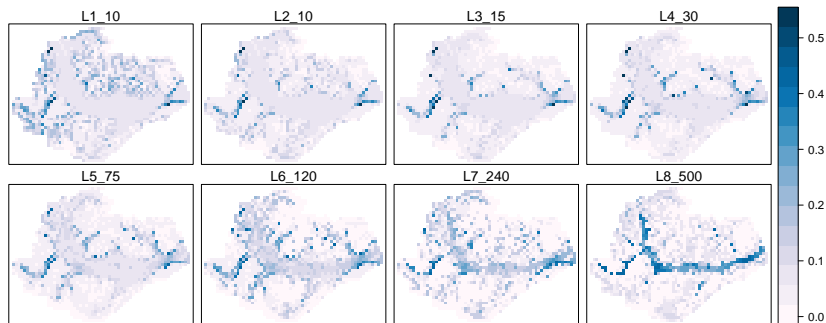
```
wpath_3D <- 'resources/simulation/Vinschgau'
basin <- get.geotop.inpts.keyword.value("LandCoverMapFile",
                                         wpath=wp_3D,raster=TRUE)
basin
```

```
## class      : RasterLayer
## dimensions  : 48, 63, 3024 (nrow, ncol, ncell)
## resolution  : 1000, 1000 (x, y)
## extent     : 598000, 661000, 5145000, 5193000 (xmin, xmax, ymin, ymax)
## coord. ref. : +proj=utm +zone=32 +ellps=WGS84 +datum=WGS84 +units=m +no_defs
## data source : in memory
## names       : layer
## values      : 1, 11 (min, max)
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Input GeoSpatial Map: Elevation and Weather Station

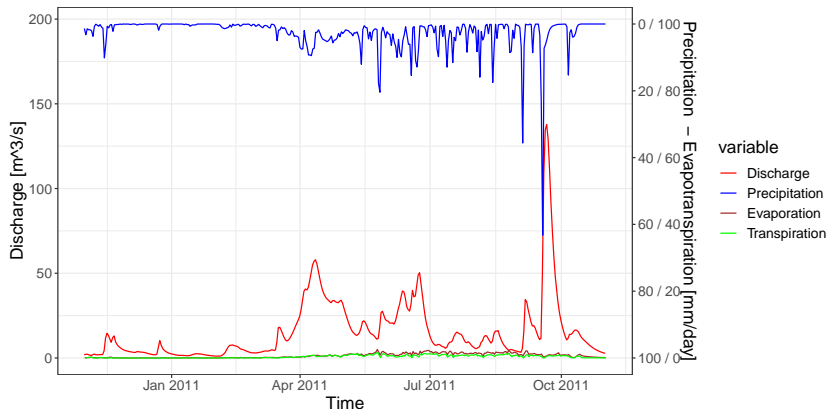


3D Spatially Distributed Simulation (Output Geospatial Map): Soil Water Content



```
help("brickFromOutputSoil3DTensor") ## for more details
```


3D Spatially Distributed Simulation (Output Geospatial Map): Surface Water Discharge at the Outlet



Dicussion

- ▶ Graphical Representation using R , useful for hydrologigists and Reaserchers;
- ▶ Open science : results accessible to a variegate community of professional, scientific or amateur people, not all hydrologigists are R users but not all R users are hydrologigists!
- ▶ Reproducible Analysis and Transparency : results can be automatically documented in reports or presentations.
- ▶ Though **geotopbricks** user can intercat between R and GEOtop using R enviroment and GEOtop keywords system indepently from the GEOtop simulation structure.

Conclusions and Way Forward

- ▶ Open Source (and not only) Hydrological Model needs powerful and FAIR interfaces to process I/O data;
- ▶ An R package working directly with GEOtop keywords facilitate the development of customized tools for specific GEOtop applications;
- ▶ Collaborations between hydrologists / modelers and R users are encouraged.

F_{indable}



A_{ccessible}



I_{nteroperable}



R_{eusable}



Finally

Aknowledgements to

- ▶ all **GEOtop** developers and users' group, in particular *Matteo Dall'Amico, Stefano Cozzini, Alberto Sartori, Stefano Endrizzi, Samuel Senoner, Riccardo Rigon*, who provided images about GEOtop and hydrologic models for this presentation
- ▶ the community of **R** whose packages allow to analize and visualise GEOtop data.

If intertested? See and follow us on (www.geotop.org) or (<https://cran.r-project.org/package=geotopbricks>)

Thank you for your attention! / Merci pour votre attention!
Find us as **@ecor** (presenter) or **@EURAC-Ecohydro** (co-authors) on *GitHub*.