

geotopbricks

An R Package for the Distributed Hydrological Model GEOtop

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github.com/ecor

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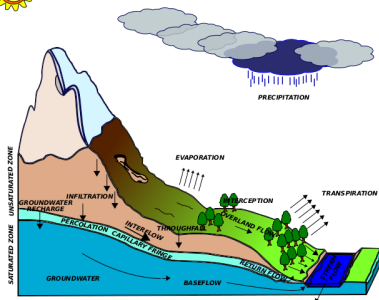
Who are we?



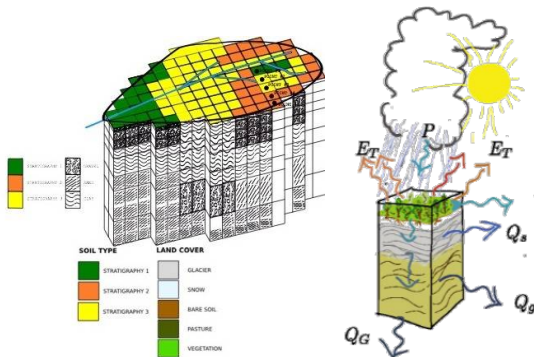
- ▶ Environmental engineers with hydrological background (more deterministic and physically-based than statics!)
- ▶ Some of us are researchers, other are self-employed and freelancers - www.rendena100.eu . - Some of us are authors of several R-packages and R enthusiast.
- ▶ Some of us are developers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

Hydrology

Scientific study of the movement, distribution, and quality of water, including the water cycle, water resources and environmental watershed sustainability.[*Wikipedia*]



Hydrological Models



Models that estimate water river discharge, soil water content, evapo-transpiration, etc.

(*output*) in function of weather forcings and soil/land/geomorphological characterization (*input*).

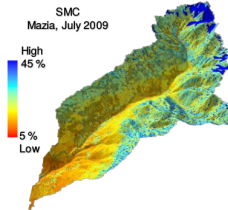
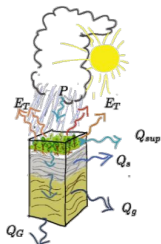
Soil water mass balance equation: $\frac{\partial \theta}{\partial t} = \nabla \cdot [K(\nabla(\psi + z_f))] + S$

Soil Heat (energy) balance equation: $C_s \frac{\partial T_s}{\partial t} = \nabla \cdot [K_t(\nabla T_s)] + \lambda S$

GEOtop Hydrological Model

GEOtop hydrological model solves water mass balance and energy balance equations coupled with the exchanges between terrain and lower atmosphere in the following two setup configurations:

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

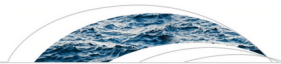


GEOtop Hydrological Model Software Package / Source Code

GEOtop Hydrological Model is an open source software package (GPL3 licence):

- ▶ 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/>.



Water Resources Research

RESEARCH ARTICLE

10.1002/2016WR019191

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 Sulis³, Reed M. Maxwell⁴, Claudio Paniconi⁵, Mario Putti⁶, Giacomo Bertoldi⁷, Ethan T. Cooper⁸, Emanuele Cordano^{7,9}, Stefano Endrizzi¹⁰, Evgeny Kikinzon⁸

Key Points:

- Seven hydrologic models were intercompared using three benchmarks of increasing complexity

Toulouse, France



geotopbricks 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
115 -----
116
117 |Urban|, 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 = 10,10,10,10,10,10,10,10,10,10
126 LAI = 0,2,5,7,7,7,0,0,0
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
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
137 CanDensSurface = 0,5,0,5,0,5,0,5,0,5,0,5,0,5,0,5
138 SoilAlbVisDry = 0,15,0,15,0,15,0,15,0,15,0,15,0,15,0,15
139 SoilAlbIRDry = 0,25,0,25,0,25,0,25,0,25,0,25,0,25,0,25
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
142 SoilEmisVis = 0,96,0,96,0,96,0,96,0,96,0,96,0,96,0,96
143 SurfLowResLand = 0,05,0,05,0,05,0,05,0,05,0,05,0,05,0,05
144 SurfLowResExp = 0,667,0,667,0,667,0,667,0,667,0,667,0,667,0,667,0,667,0
145
146 -----
147 ! SOIL
148 -----
149
150 -----
151 on_Period,Run,1Dpoint,Fenow_over_canopy(mm),FRAIN_over_canopy(mm),Fenow_and
152 0,000000,0,000000,2,000000,0,000000,0,594534,845,935673,-2,515065,-9,571513,
153 0,000000,0,000000,2,000000,0,000000,0,540388,845,935673,-1,276736,-9,737498,
154 0,000000,0,000000,2,000000,0,000000,0,621824,845,935673,-1,066188,-7,640795,
155 0,000000,0,000000,2,000000,0,000000,0,600711,845,935673,-1,294093,-8,254263,
156 0,007902,0,000000,2,000000,0,000000,0,662947,845,935673,-3,019611,-8,706343,
157 0,004654,0,000000,2,000000,0,000000,0,737405,845,935673,-2,355446,-6,556768,
158 0,000000,0,000000,2,000000,0,000000,0,786185,845,935673,-2,654789,-6,304200,
159 0,000000,0,000000,2,000000,0,000000,0,757363,845,935673,-3,869414,-7,918764,
160 0,000000,0,000000,2,000000,0,000000,0,858772,845,935673,-3,204810,-5,457861,
161 0,000000,0,000000,2,000000,0,000000,0,870951,845,935673,-1,870901,-3,545580,
162 0,000000,0,000000,2,000000,0,000000,0,822212,845,935673,-1,359526,-3,724409,
163 0,000000,0,000000,2,000000,0,000000,0,863171,845,935673,-1,552101,-3,744007,
164 0,000000,0,000000,2,000000,0,000000,0,822099,845,935673,-1,265422,-4,147197,
165 0,000000,0,000000,2,000000,0,000000,0,793820,845,935673,-2,205546,-5,612859,
166 0,000000,0,000000,2,000000,0,000000,0,869562,845,935673,-0,997046,-3,064751,
167 0,000000,0,000000,2,000000,0,000000,0,651825,845,935673,-2,655292,-3,952574,
168 0,000000,0,000000,2,000000,0,000000,0,263767,845,935673,-3,89195,-13,677723,
169 0,000000,0,000000,2,000000,0,000000,0,197345,845,935673,-0,263096,-20,94291,
170 0,000000,0,000000,2,000000,0,000000,0,232248,845,935673,-0,767446,-19,51957,
171 0,009736,0,000000,2,000000,0,000000,0,315342,845,935673,0,751874,-14,531958,
172 0,000000,0,000000,2,000000,0,000000,0,439699,845,935673,2,329386,-9,113440,
173 0,000000,0,000000,2,000000,0,000000,0,791622,845,935673,2,012167,-1,549791,
174 0,000000,0,000000,2,000000,0,000000,0,856759,845,935673,0,725297,-1,649403,
175 0,000000,0,000000,2,000000,0,000000,0,843911,845,935673,-0,920365,-3,433401,
176 0,736426,0,034357,2,000000,0,000000,0,816958,845,935673,-1,625877,-4,523464,
177 0,825246,0,289262,2,000000,0,000000,0,475254,845,935673,-1,256377,-11,12331,
178 0,026978,0,026978,2,000000,0,000000,0,589751,845,935673,-0,756201,-10,91388,
179 3,0,000000,0,000000,2,000000,0,000000,0,910178,845,935673,-3,378619,-8,4542,
180 0,477926,0,477926,2,000000,0,000000,0,873055,845,935673,-0,400006,-2,331174,
181 0,040732,0,035976,2,000000,0,000000,0,735867,845,935673,-0,046195,-1,332321,
182 0,000339,0,000199,2,000000,0,000000,0,705903,845,935673,-0,849916,-6,438780,
183 0,000871,0,000446,2,000000,0,000000,0,542817,845,935673,-0,894400,-9,186285,
184 0,041915,0,041915,2,000000,0,000000,0,687120,845,935673,-1,791830,-6,910850,
185 0,004844,0,002789,2,000000,0,000000,0,567434,845,935673,-2,316165,-10,75937,
186 0,000000,0,000000,2,000000,0,000000,0,298915,845,935673,-0,718051,-16,57952,
187 0,000000,0,000000,2,333328,0,000000,0,398800,986,522800,0,522255,-16,961183
```

GEOtop Simulation Configuration File (geotop.inpts)

GEOtop simulation is a directory containing a configuration file, called **geotop.inpts** filled with a keywords system addressing to simulation options (e.g. simulation period); **input files** (e.g. meteorological forcings, soil and geomorphology of the basin); **output files** (spatio-temporal maps - raster and time series - of the results).

```
InitDateDDMMYYYYhhmm=09/04/2014 18:00  
EndDateDDMMYYYYhhmm =01/01/2016 00:00  
[...]  
MeteoFile              ="meteoB2_irr"  
PointOutputFile        ="tabs/point"
```

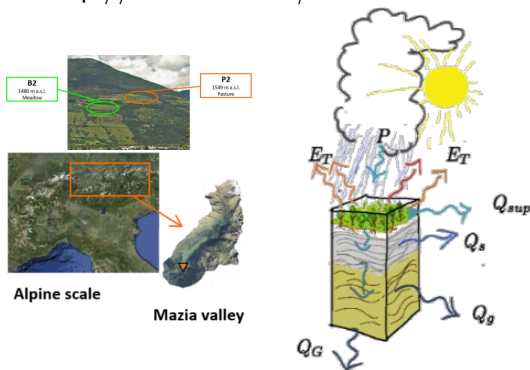

geotopbricks R Package: What it Does

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

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

1D GEOTop Simulation in an Alpine Site: 2 Points

Estimation of soil water content (SWC) in two points **P2** and **B2** located in Val Mazia/Matsch, South Tyrol, Italy
<http://lter.eurac.edu/en>.



B2



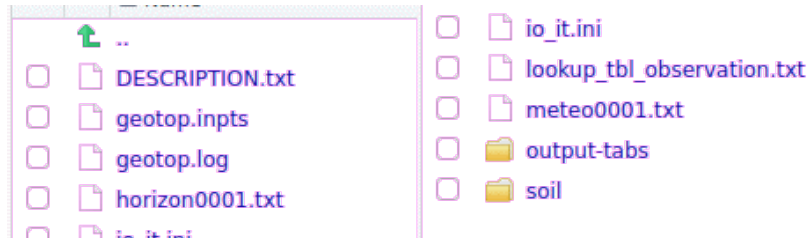
1D GEOTop Simulation in an Alpine Site: B2

Here is the directory containing files of B2 point simulation:

```
library(geotopbricks)
```

```
## SET GEOTOP SIMULATION DIRECTORY
```

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



Getting Simulation Input Data

Meteorological forcings 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)

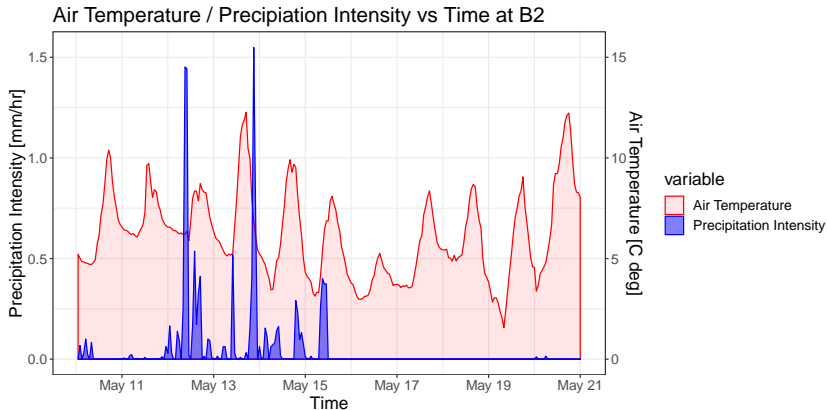
Meteorological time series once imported can be printed:

```
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")])
```

Precipitation and Air Temperature at B2



Getting Simulation Output Data

Soil Water Content Profile:

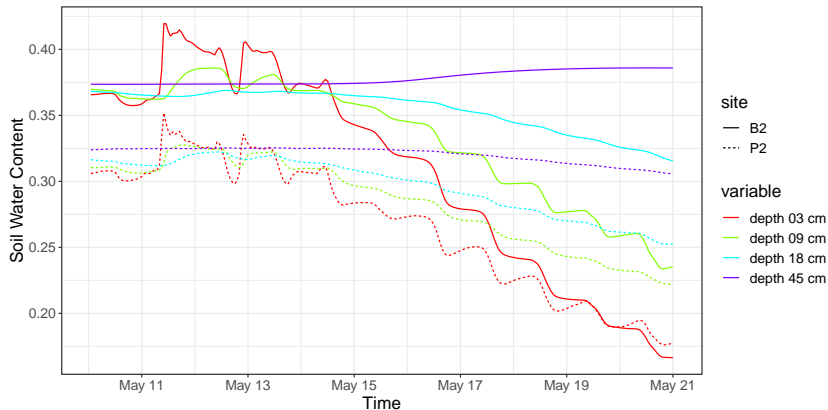
```
tz <- "Etc/GMT-1"
SWC_B2 <- get.geotop.inpts.keyword.value(
  "SoilLiqContentProfileFile",
  wpath = wpath_B2,
  data.frame = TRUE,
  date_field = "Date12.DDMMYYYYhhmm.",
  tz = tz,
  zlayer.formatter = "z%04d"
)
help(get.geotop.inpts.keyword.value) ## for more details!
```

Getting Simulation Output Data (at P2)

Analogously 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

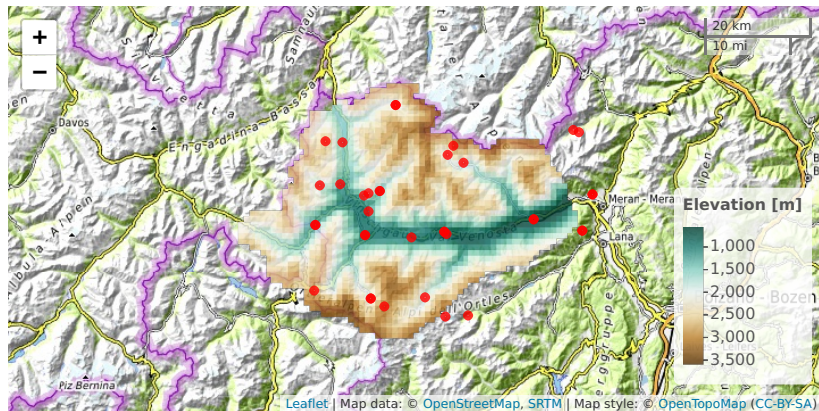


3D Spatially Distributed Simulation: Val Venosta/Vinschgau - Upper Adige River Basin - Alps - I/CH/A

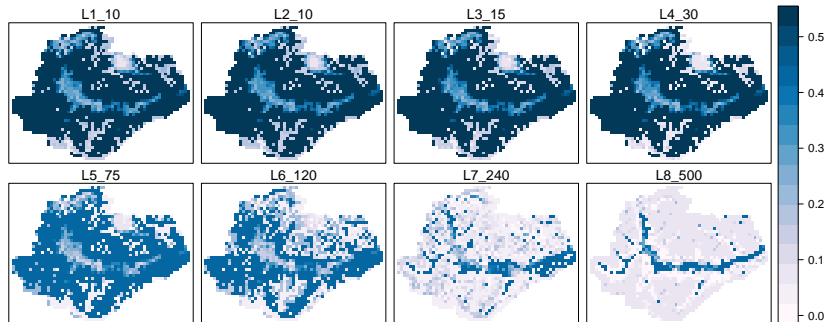
```
wpath_3D <- 'resources/simulation/Vinschgau'
basin <- get.geotop.inpts.keyword.value("LandCoverMapFile",
                                         wpath=wp_3D,raster=TRUE)
basin
```

```
## 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)
```

Input GeoSpatial Map: Elevation and Weather Station

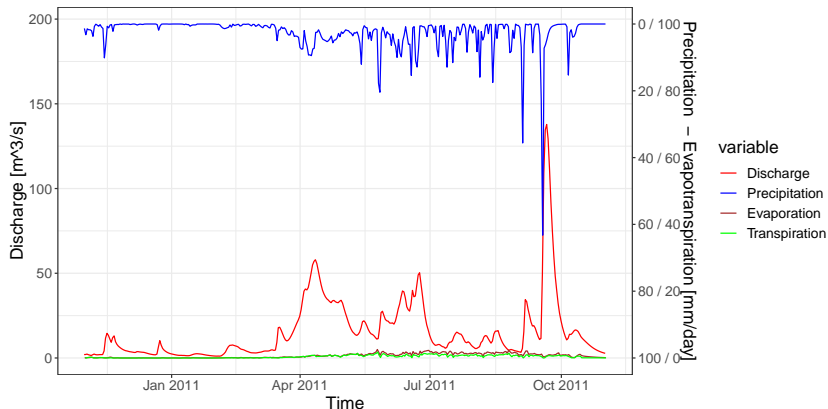


3D Spatially Distributed Simulation (Output Geospatial Map): Soil Water Content



```
brickFromOutputSoil3DTensor("SoilLiqContentTensorFile",  
wpath=wpath_3D,when="2011-08-16 12:00:00 +01")
```

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

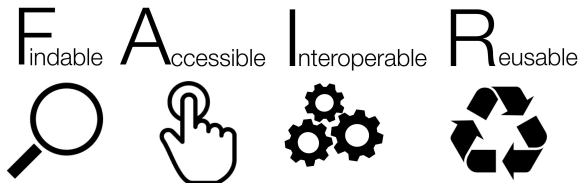


Discussion

- ▶ **geotopbricks** allows graphical representation using R of GEOtop results , useful for hydrologigists and reaserchers;
- ▶ Through **geotopbricks** user can interact between R and GEOtop using R enviroment and GEOtop keywords system, without using the GEOtop simulation structure.
- ▶ Processing of a GEOtop simulation is always reproducible for any other simulation; results can be automatically documented in reports or presentations.

Conclusions and Way Forward

- ▶ **geotopbricks** is an interface of GEOtop in R speaking the language of GEOtop;
- ▶ R code based on **geotopbricks** can help the implementation of further package or apps: analytics, model calibration, visualization.
- ▶ Open Source (and not only) Hydrological Model needs powerful interfaces to process I/O in a FAIR way;



Finally

Aknowledgements to

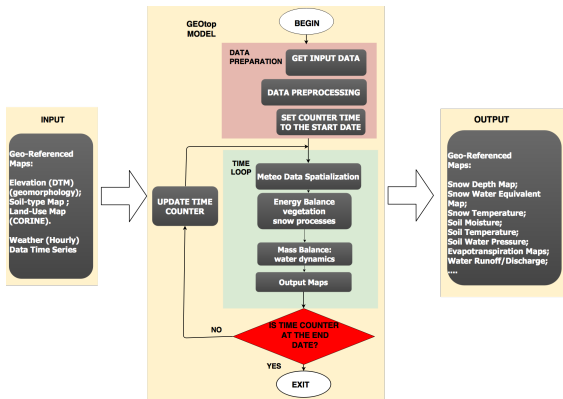
- ▶ all **GEOTop** developers and users' group, in particular **Matteo Dall'Amico, Stefano Cozzini, Alberto Sartori, Stefano Endrizzi, Samuel Senoner, Riccardo Rigon**, who provided images about GEOTop for this presentation
- ▶ the community of **R** whose packages allow to analize and visualise GEOTop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

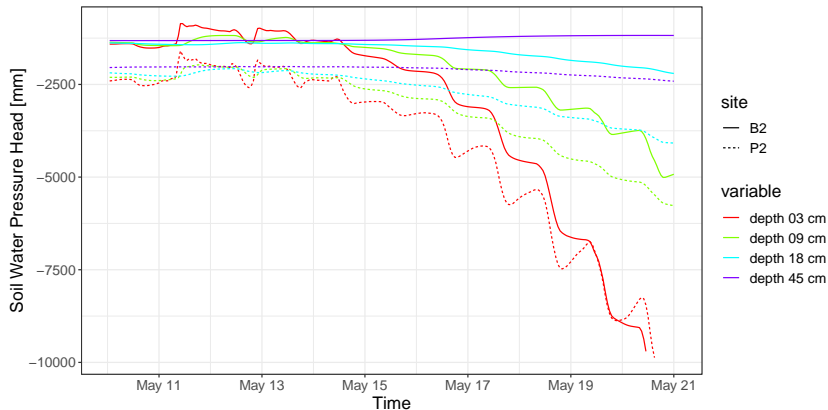
Addendum

GEOtop Hydrological Model Flowchart



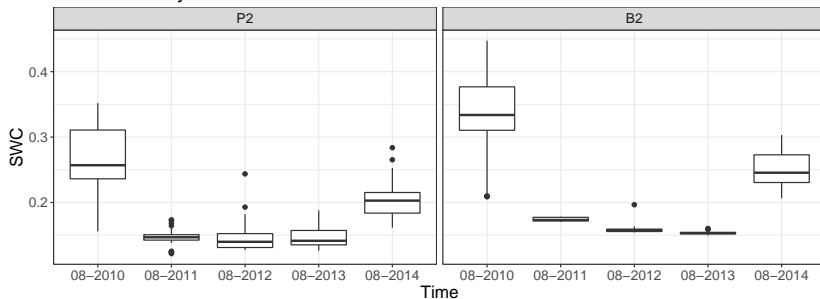
- **Input:** meteo data, elevations, soil parameters, . . .
- **Output:** snow cover, soil temperature, soil moisture, . . .

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 **eRum2018** poster.