geotopbricks

An R Package for the Distributed Hydrological Model GEOtop

Emanuele Cordano (Rendena100)

github.com/ecor

Giacomo Bertoldi , Elisa Bortoli (EURAC Ecohydro)

github.com/Ecohydro

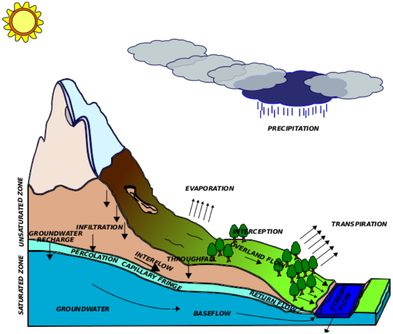
Who are we?



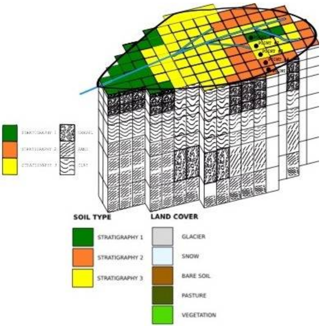
- Environmental engineers with hydrological background (more deterministic and physically-based than statics!)
- Some of us are researchers, other are self-employed and freelancers - www.rendena100.eu . - Some of us are authors of several R-packages and R enthusiast.
- Some of us are developers of GEOtop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

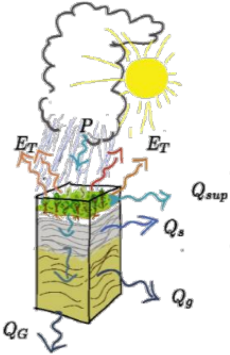
Hydrology

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*).

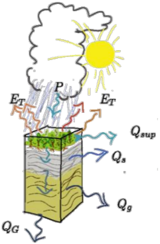
Soil water mass balance equation: $\frac{\partial \theta}{\partial t} = \nabla \cdot [K\,(\nabla(\psi + z_f))] + S$

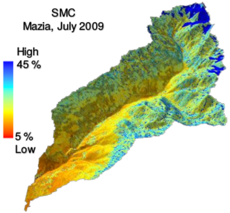
Soil Heat (energy) balance equation: $C_s \frac{\partial T_s}{\partial t} = \nabla \cdot [K_t(\nabla T_s)] + \lambda S$

GEOtop Hydrological Model

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

- **1D**: only vertical fluxes $\rightarrow$ balances at local scale (only in one soil column)
- **3D**: vertical and lateral fluxes $\rightarrow$ 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/.

AGU PUBLICATIONS

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 Sulis[3], Reed M. Maxwell[4], Claudio Paniconi[5], Mario Putti[6], Giacomo Bertoldi[7], Ethan T. Coon[8], Emanuele Cordano[7,9], Stefano Endrizzi[10], Evgeny Kikinzon[8]

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

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*)

geotop.inpts

```
!========================================
! LAND COVER
!========================================

!Urban1,    Pasture 2,  Grassland 3,    Agricultural 4, Broad leaf forest 5,
!Bare Rocks 8,  Bare Soils 9,   Glacier 10, Lake/Marsh 11

NumLandCoverTypes   =   11
SoilRoughness   =   1,10,10,10,10,10,10,10,10,1,1
ThresSnowSoilRough  =   10,10,10,10,10,10,10,10,10,10,10
VegHeight   =   0,200,600,600,1900,1900,1900,0,0,0,0
ThresSnowVegUp  =   50,50,50,50,50,50,50,50,50,50,50
ThresSnowVegDown    =   10,10,10,10,10,10,10,10,10,10,10
LSAI    =   0,2,5,5,7,7,7,0,0,0,0
CanopyFraction  =   0,0.7,1,1,1,1,1,0,0,0,0
DecayCoeffCanopy    =   2.5,2.5,2.5,2.5,2.5,2.5,2.5,2.5,2.5,2.5,2.5
VegSnowBurying  =   1,1,1,1,1,1,1,1,1,1,1
RootDepth   =   0,200,300,500,700,700,700,0,0,0,0
MinStomatalRes  =   60,60,60,60,60,60,60,60,60,60,60
VegReflectVis   =   0.1,0.1,0.1,0.1,0.1,0.1,0.1,0.1,0.1,0.1
VegReflNIR  =   0.58,0.58,0.58,0.58,0.58,0.58,0.58,0.58,0.58,0.58
VegTransVis =   0.05,0.05,0.05,0.05,0.05,0.05,0.05,0.05,0.05,0.05,0.05
VegTransNIR =   0.25,0.25,0.25,0.25,0.25,0.25,0.25,0.25,0.25,0.25,0.25
LeafAngles  =   0,0,0,0,0,0,0,0,0,0,0
CanDensSurface  =   0.5,0.5,0.5,0.5,0.5,0.5,0.5,0.5,0.5,0.5,0.5
SoilAlbVisDry   =   0.15,0.15,0.15,0.15,0.15,0.15,0.15,0.15,0.15,0.15,0.15
SoilAlbNIRDry   =   0.25,0.25,0.25,0.25,0.25,0.25,0.25,0.25,0.25,0.25,0.25
SoilAlbVisWet   =   0.15,0.15,0.15,0.15,0.15,0.15,0.15,0.15,0.15,0.15,0.15
SoilAlbNIRWet   =   0.25,0.25,0.25,0.25,0.25,0.25,0.25,0.25,0.25,0.25,0.25
SoilEmissiv =   0.96,0.96,0.96,0.96,0.96,0.96,0.96,0.96,0.96,0.96,0.96
SurFlowResLand  =   0.05,0.05,0.05,0.05,0.05,0.05,0.05,0.05,0.05,0.05,0.05
SurFlowResExp   =   0.667,0.667,0.667,0.667,0.667,0.667,0.667,0.667,0.667,0.

 ========================================
! SOIL
!========================================

```

point0001.txt

```
on_Period,Run,IDpoint,Psnow_over_canopy[mm],Prain_over_canopy[mm],Psnow_und
.000000,0.000000,2.000000,0.000000,0.594534,845.935673,-2.515065,-9.571513,
.000000,0.000000,2.000000,0.000000,0.540388,845.935673,-1.276736,-9.737498,
.000000,0.000000,2.000000,0.000000,0.621824,845.935673,-1.066188,-7.640795,
.000000,0.000000,2.000000,0.000000,0.600711,845.935673,-1.294093,-8.284263,
.007902,0.000000,2.000000,0.000000,0.662947,845.935673,-3.019611,-8.706343,
.004654,0.000000,2.000000,0.000000,0.737405,845.935673,-2.355446,-6.586768,
.000000,0.000000,2.000000,0.000000,0.786185,845.935673,-2.654789,-6.304200,
.000000,0.000000,2.000000,0.000000,0.757363,845.935673,-3.868414,-7.918764,
.000000,0.000000,2.000000,0.000000,0.858772,845.935673,-3.204810,-5.457861,
0.000000,0.000000,2.000000,0.000000,0.870957,845.935673,-1.470907,-3.548580
0.000000,0.000000,2.000000,0.000000,0.852212,845.935673,-1.358926,-3.724409
0.000000,0.000000,2.000000,0.000000,0.863171,845.935673,-1.552901,-3.744007
0.000000,0.000000,2.000000,0.000000,0.822099,845.935673,-1.265422,-4.147197
0.000000,0.000000,2.000000,0.000000,0.793820,845.935673,-2.205560,-5.612589
0.000000,0.000000,2.000000,0.000000,0.869562,845.935673,-0.997046,-3.064751
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0.000000,0.000000,2.000000,0.000000,0.263767,845.935673,4.368195,-13.677723
0.000000,0.000000,2.000000,0.000000,0.197345,845.935673,-0.063096,-20.96291
0.000000,0.000000,2.000000,0.000000,0.232248,845.935673,-0.767446,-19.51957
0.009736,0.000000,2.000000,0.000000,0.315342,845.935673,0.751874,-14.531958
0.000000,0.000000,2.000000,0.000000,0.439699,845.935673,2.329386,-9.113440,
0.000000,0.000000,2.000000,0.000000,0.791622,845.935673,2.012167,-1.569791,
0.000000,0.000000,2.000000,0.000000,0.856799,845.935673,0.725297,-1.649403,
0.000000,0.000000,2.000000,0.000000,0.843913,845.935673,-0.920365,-3.433401
0.736428,0.034357,2.000000,0.000000,0.816958,845.935673,-1.625578,-4.523464
0.325246,0.289256,2.000000,0.000000,0.475254,845.935673,-1.256837,-11.12231
0.026978,0.026978,2.000000,0.000000,0.588791,845.935673,-3.756201,-10.91388
3,0.000000,0.000000,2.000000,0.000000,0.910178,845.935673,-3.378619,-4.6542
0.477926,0.477926,2.000000,0.000000,0.873055,845.935673,-0.400006,-2.331174
0.040732,0.035976,2.000000,0.000000,0.735867,845.935673,-0.046199,-4.332921
0.000339,0.000199,2.000000,0.000000,0.705903,845.935673,-0.569916,-5.438780
0.000871,0.000446,2.000000,0.000000,0.542817,845.935673,-0.894400,-9.186285
0.041919,0.041919,2.000000,0.000000,0.687120,845.935673,-1.791830,-6.910850
0.004844,0.002789,2.000000,0.000000,0.567434,845.935673,-2.316168,-10.75837
0.000000,0.000000,2.000000,0.000000,0.299119,845.935673,-0.718052,-16.57892
0.000000.0.000000.2.333328.0.000000.0.398800.986.922800.0.522255.-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"
```

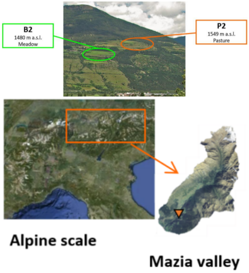
geotopbricks R Package: What it Does

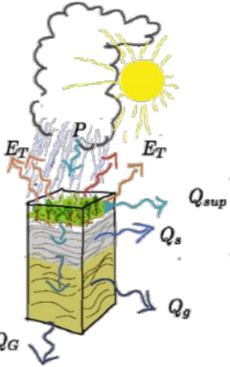
The aim of **geotopbricks** , starting in 2013, is to import all GEOtop simulaton data into the **R** environment by using the *keyword-value* syntax of *geotop.inpts*. **geotopbricks** does the following actions:

- 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.



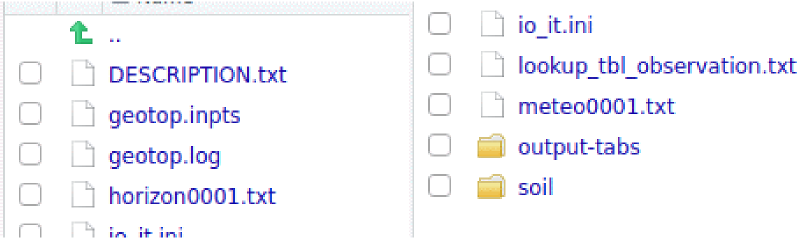


1D GEOtop Simulation in an Alpine Site: B2

Here is the directory containing files of B2 point simulation:

```r
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)

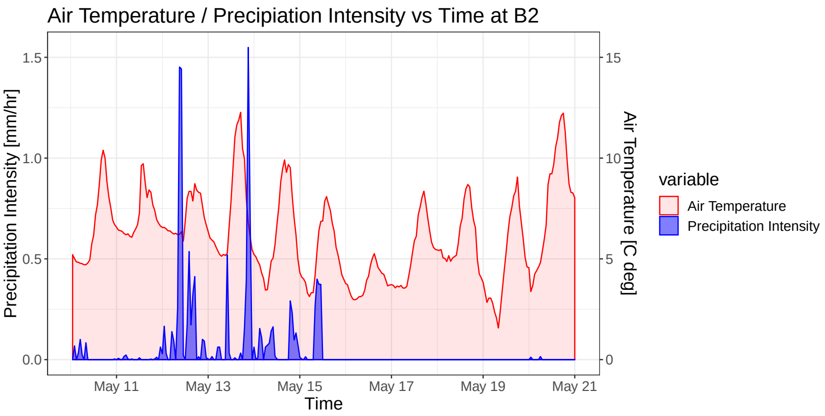
Meteorological time series once imported can be printed:

```r
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
```

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

Precipitation and Air Temperature at B2



Getting Simulation Output Data

Soil Water Content Profile:

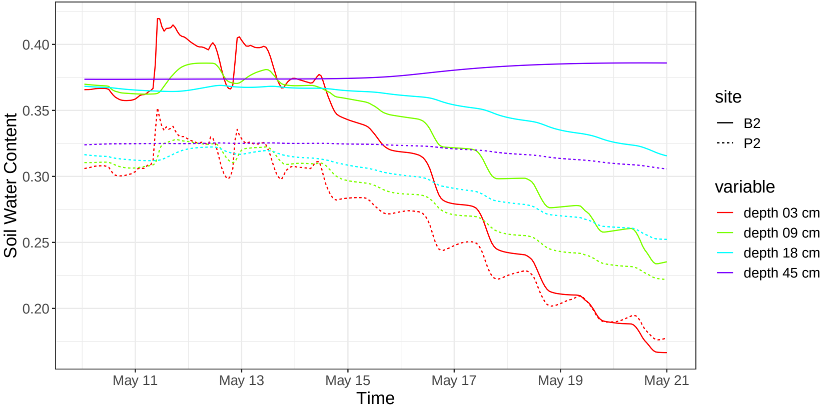
```
tz <- "Etc/GMT-1"
SWC_B2  <- get.geotop.inpts.keyword.value(
  "SoilLiqContentProfileFile",
  wpath = wpath_B2,
  data.frame = TRUE,
  date_field = "Date12.DDMMYYYYhhmm.",
  tz = tz,
  zlayer.formatter = "z%04d"
)
help(get.geotop.inpts.keyword.value) ## for more details!
```

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

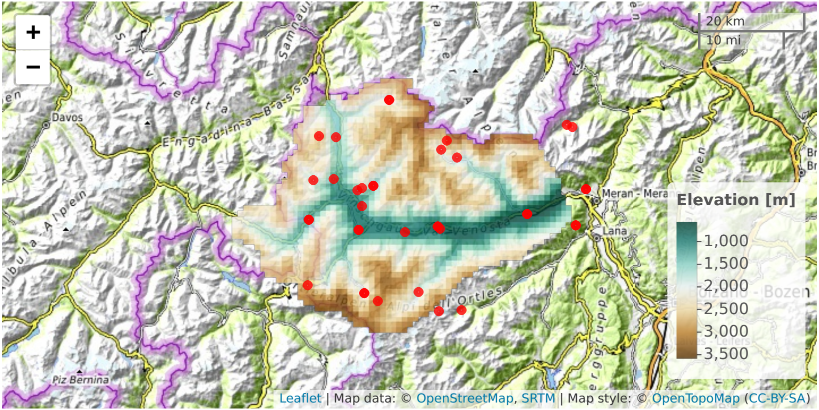


3D Spatially Distributed Simulation: Val Venosta/Vinschgau - Upper Adige River Basin - Alps - I/CH/A

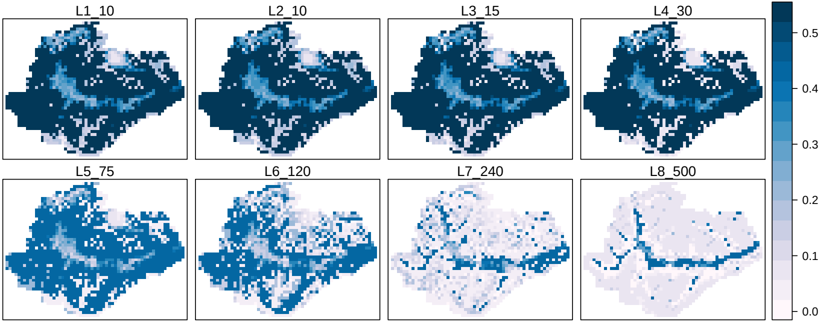
```
wpath_3D <- 'resources/simulation/Vinschgau'
basin <- get.geotop.inpts.keyword.value("LandCoverMapFile",
                wpath=wpath_3D,raster=TRUE)
basin
```

```
## class       : RasterLayer
## dimensions  : 48, 63, 3024  (nrow, ncol, ncell)
## resolution  : 1000, 1000  (x, y)
## extent      : 598000, 661000, 5145000, 5193000  (xmin, x
## coord. ref. : +proj=utm +zone=32 +ellps=WGS84 +datum=WGS
## data source : in memory
## names       : layer
## values      : 1, 11  (min, max)
```

Input GeoSpatial Map: Elevation and Weather Station

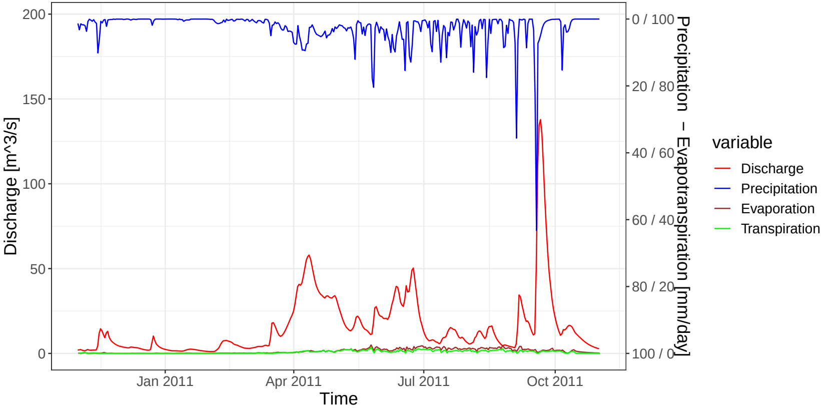


3D Spatially Distributed Simulation (Output Geospatial Map): Soil Water Content




```
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

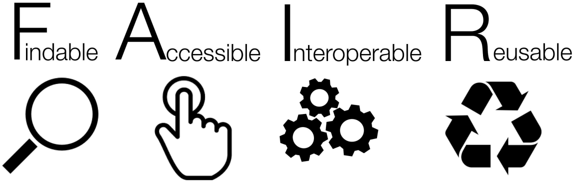


Discussion

- **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: analityics, model calibration, visualization.
- Open Source (and not only) Hydrological Model needs powerful interfaces to process I/O in a FAIR way;



Finally

Aknowledgements to

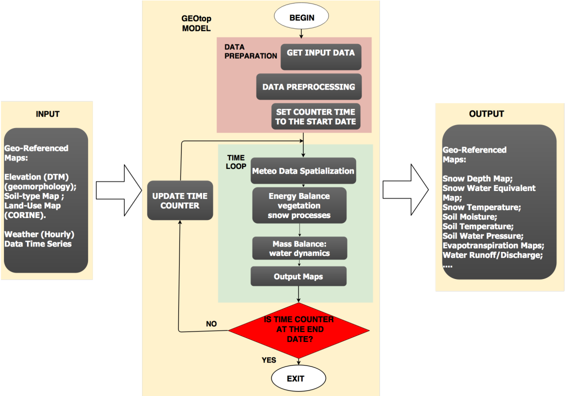
- all **GEOtop** developers and users' group, in particular **Matteo Dall'Amico, Stefano Cozzini, Alberto Sartori, Stefano Endrizzi, Samuel Senoner, Riccardo Rigon**, who provided images about GEOtop for this presentation
- the community of **R** whose packages allow to analize and visualise GEOtop data.

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*.

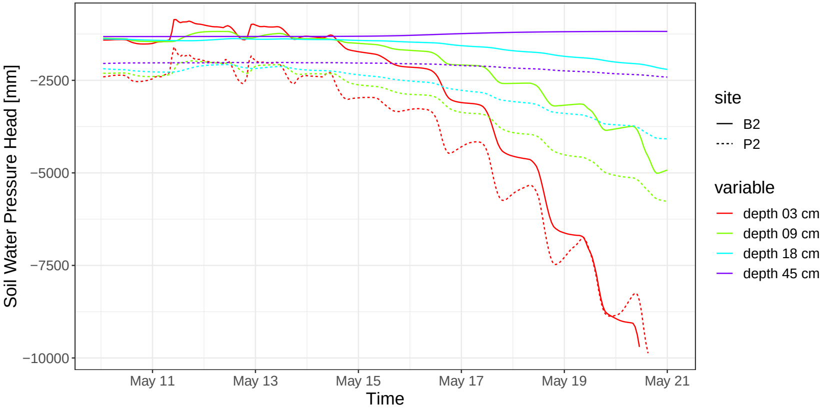
Addendum

GEOtop Hydrological Model Flowchart



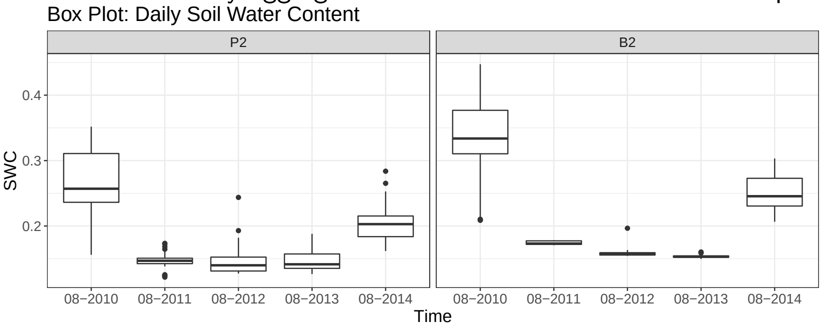
- **Input**: meteo data, elevations, soil parameters,. . .
- **Output**: snow cover, soil temperature, soil moisture,. . .

Soil Water Pressure Head at P2 and B2



Example of an Output Data Analytics (Soil Moisture Distribution)

Distribution of daily aggregated soil water contant at a 18 cm depth:



More details on the **eRum2018** poster.