geotopbricks

An R Package for the Distributed Hydrological Model GEOtop

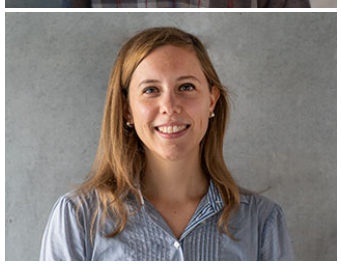
Emanuele Cordano (Rendena100)

github.com/ecor

Giacomo Bertoldi , Elisa Bortoli (EURAC Ecohydro)

github.com/Ecohydro

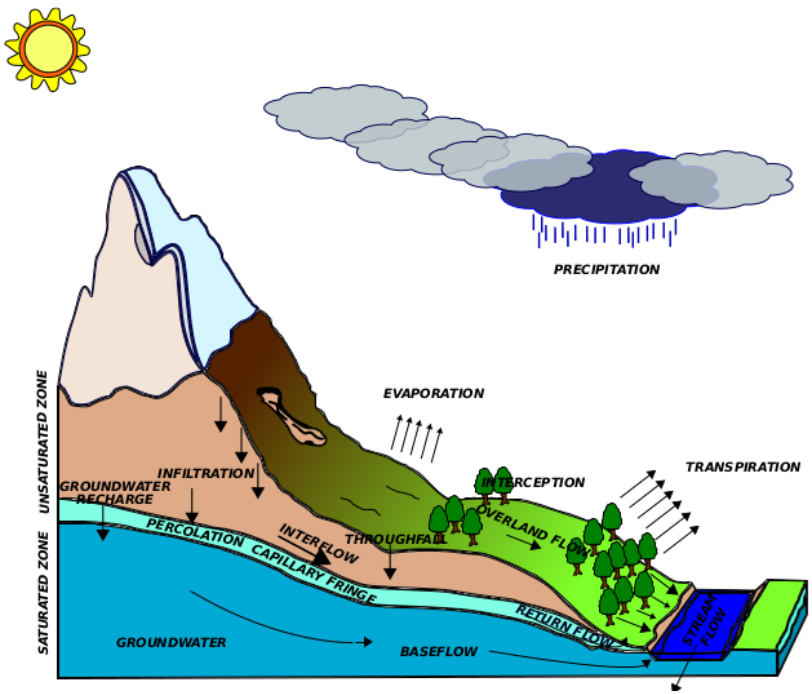
Who are we?



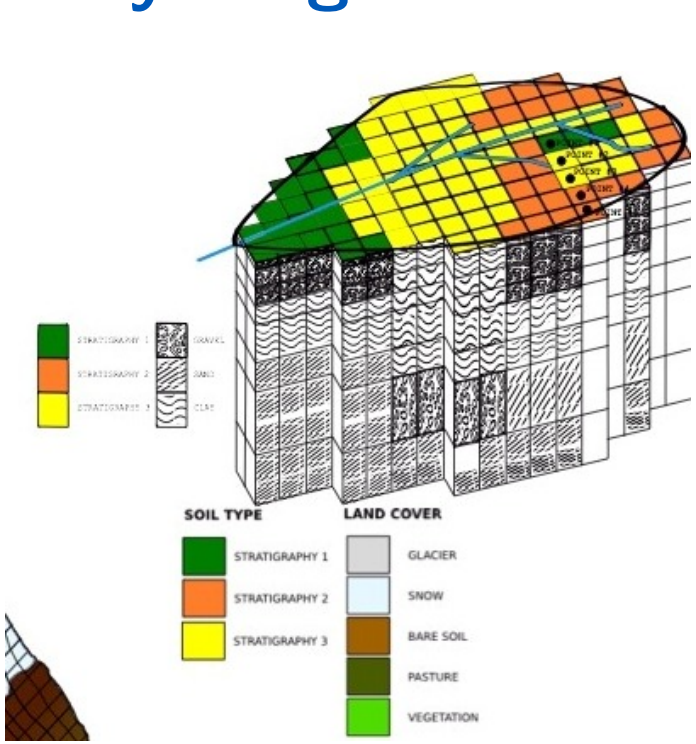
- Environmental engineers with hydrological background (more deterministic and physicall-based than statics!)
- Some of us are reserchers, other are self-employed and freelancers - www.rendena100.eu .
- Some of us are authors of several R-packages and R enthusiast.
- Some of us are developers of GEOtop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

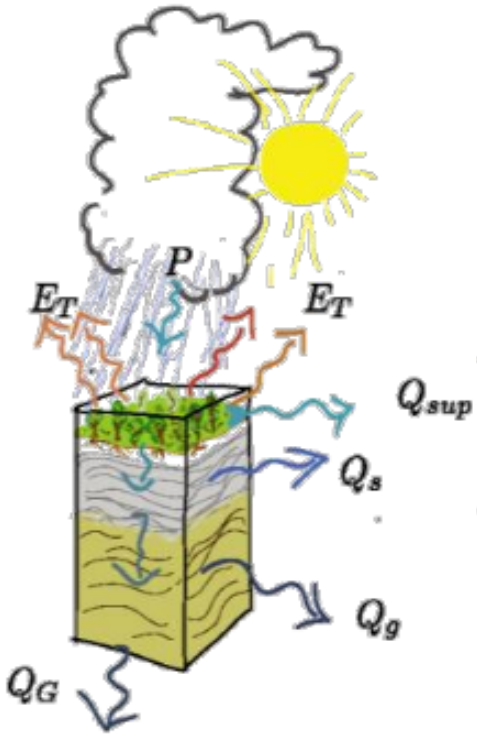
Hydrology

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



Hydrolgical models





Models that calculates water river discharge, soil water content,evapotranspiration, etc. (*output*) in function of weather time series and soil/land/geomorphological characterization (*input*).

Soil water mass balance equation:

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

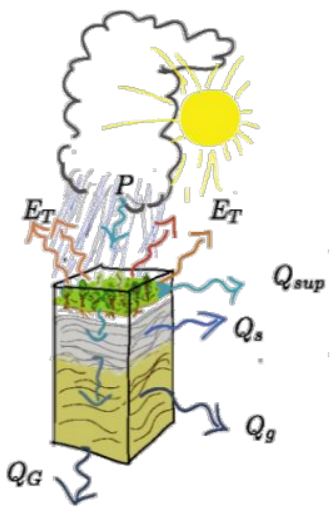
Soil Heat (energy) balance equation:

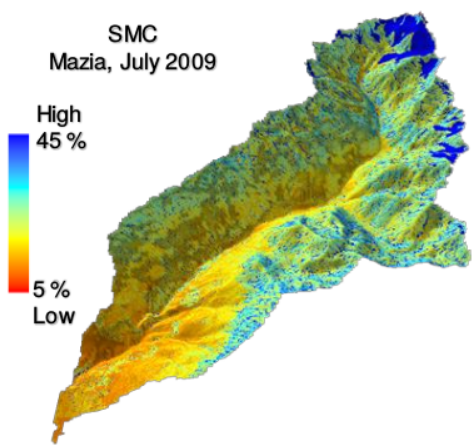
$$C_s \frac{\partial T_s}{\partial t} = \nabla \cdot [K_t(\nabla T_s)] + \lambda S + ...$$

GEOtop Hydrological Model

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

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



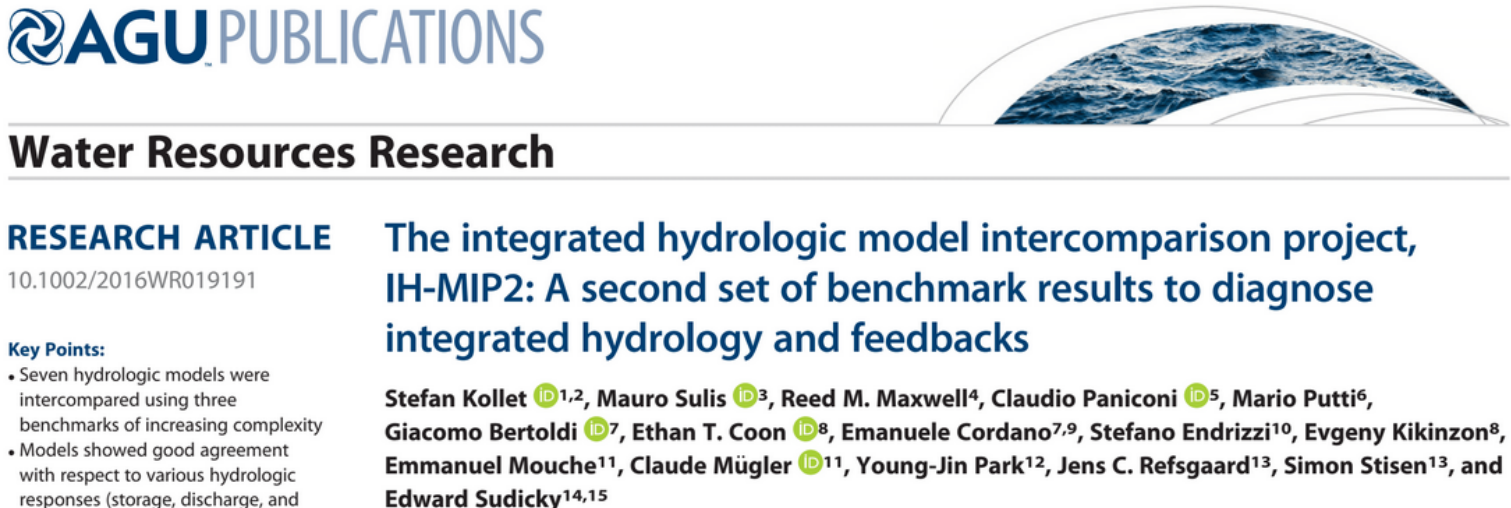


GEOtop Hydrological Model Software Package / Source Code

Core components of GEOtop software packages are:

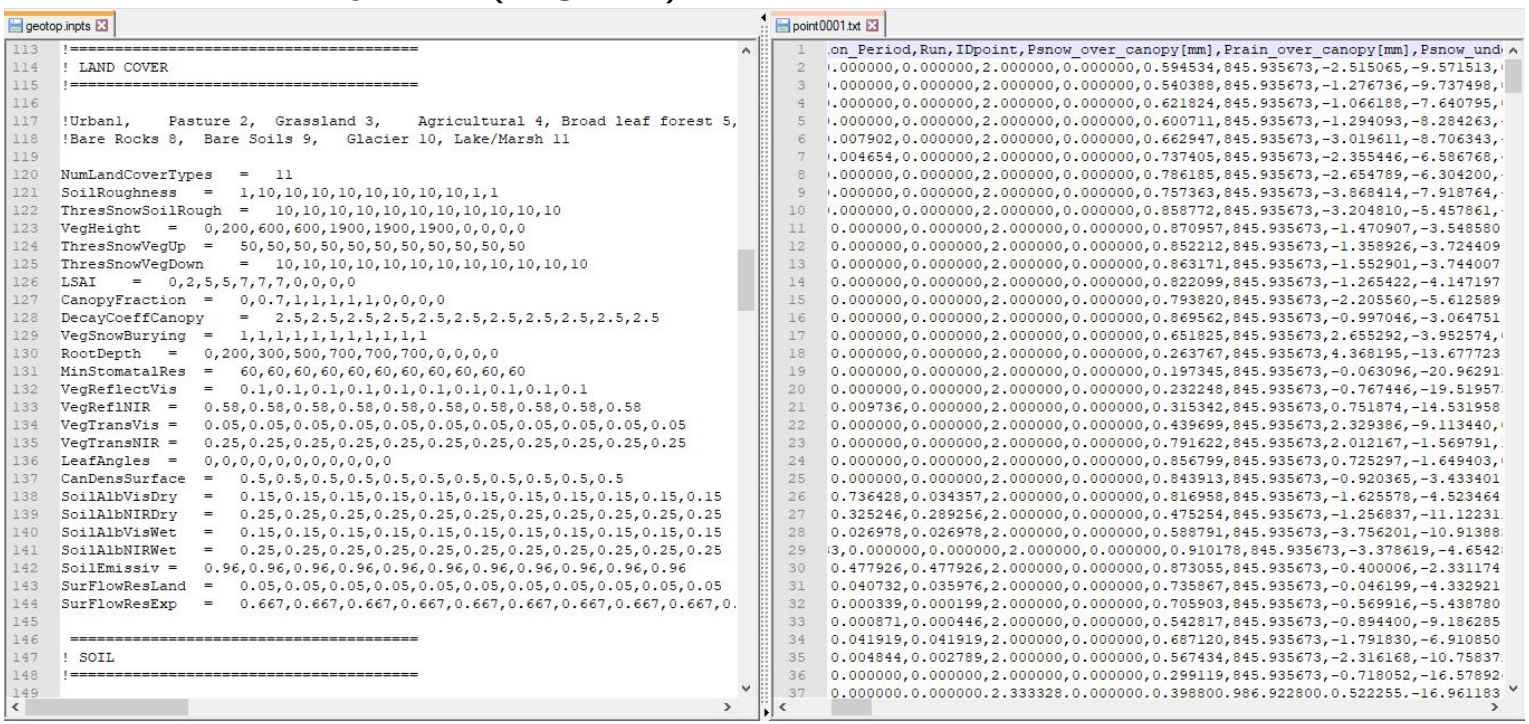
- written in C/C++
- released in 2014 (version 2.0) as free open-source project, a re-engineering process is going to finish (version 3.0);
- scientifically tested and published;

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



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  =   0.58,0.58,0.58,0.58,0.58,0.58,0.58,0.58,0.58,0.58,0.58
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
0.000000,0.000000,2.000000,0.000000,0.651825,845.935673,2.655292,-3.952574,
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)

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), **input files** (e.g. meteorological time series, soil and geomorphology of the basin), **output files** (spatio-temporal maps of the results).

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

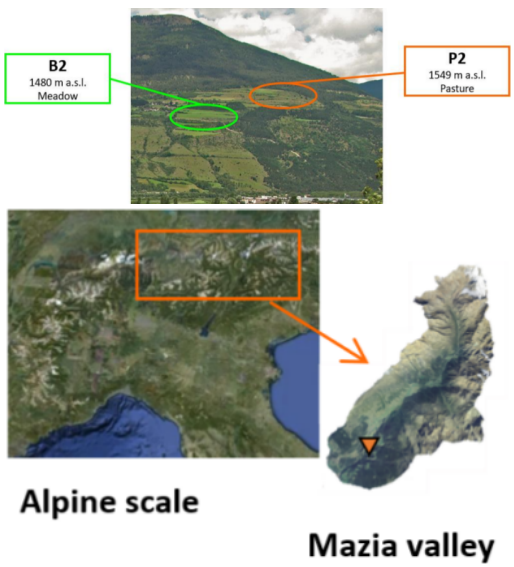
geotopbricks R package: what it does

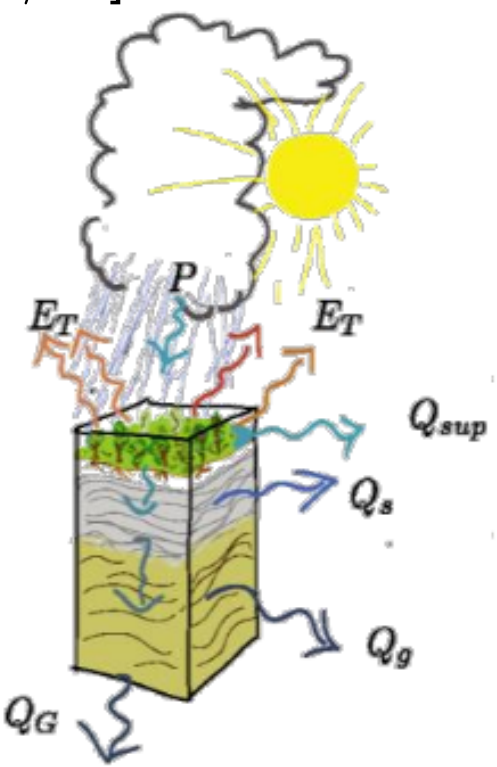
The aim of **geotopbricks** , starting in 2013, is to bring all the data of a GEOtop simulaton into the powerful statistical **R** environment by using the `keyword-value` syntax of *geotop.inpts*. **geotopbricks** does the following actions:

- 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].





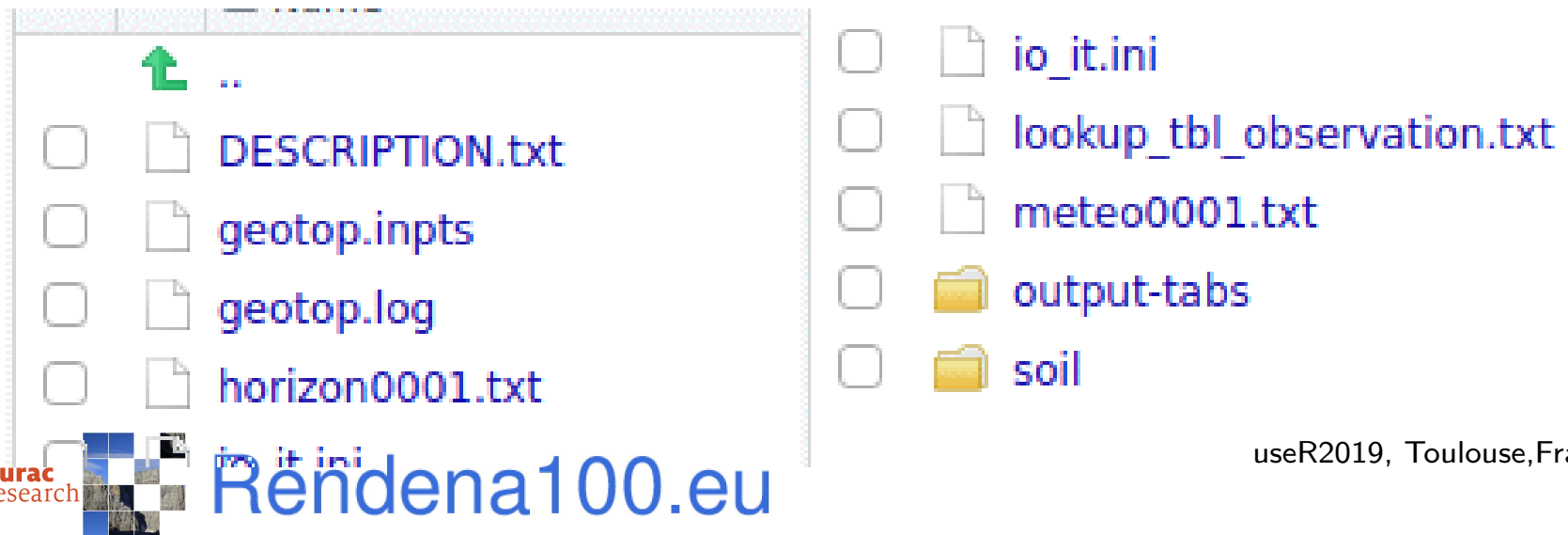
B2

Simulation of soil water budget in an alpine site

Here is the directory containing files of B2 point simulation:

```
library(geotopbricks)

## SET GEOTOP SIMULATION 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)

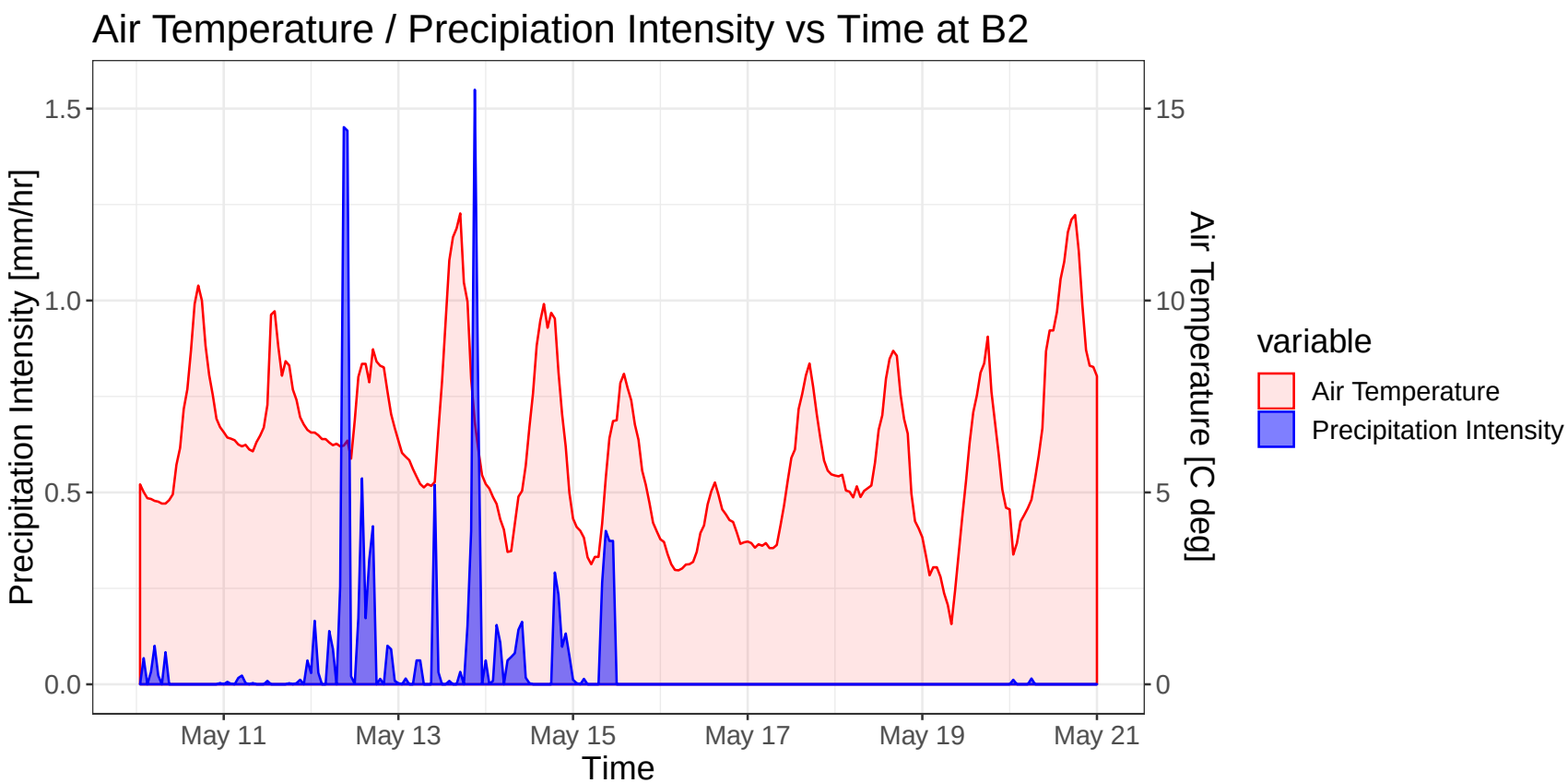
Meteorological time series once imported are available in the R environment:

```
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 at B2



Getting results of the simulation at B2

Soil Water Content Profile:

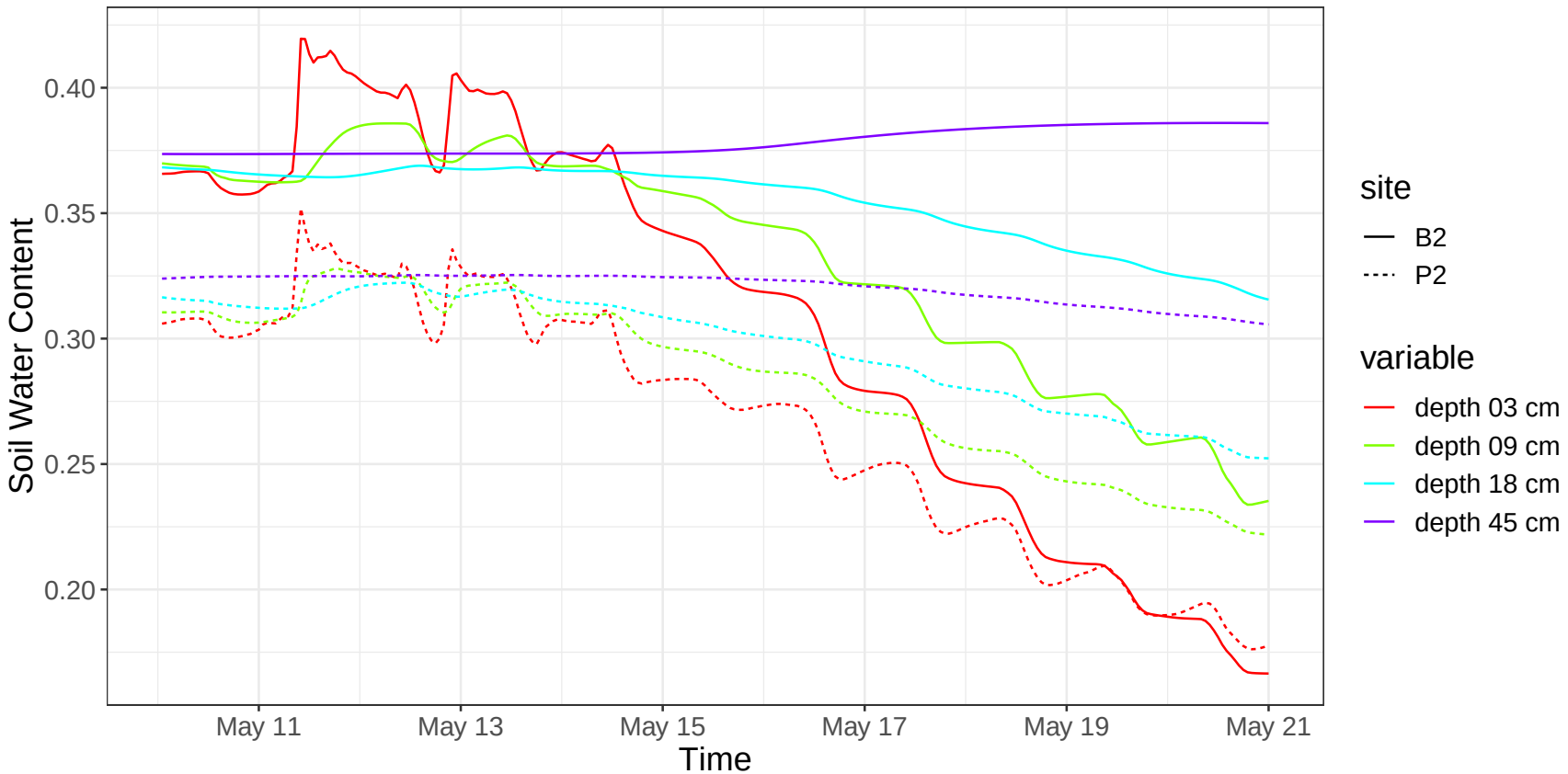
```
tz <- "Etc/GMT-1"
SWC_B2  <- get.geotop.inpts.keyword.value(
  "SoilLiqContentProfileFile",
  wpath = wpath_B2,
  data.frame = TRUE,
  date_field = "Date12.DDMMYYYYhhmm.",
  tz = tz,
  zlayer.formatter = "z%04d"
)
help(get.geotop.inpts.keyword.value) ## for more details!
```

Getting results of the simulation at P2

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

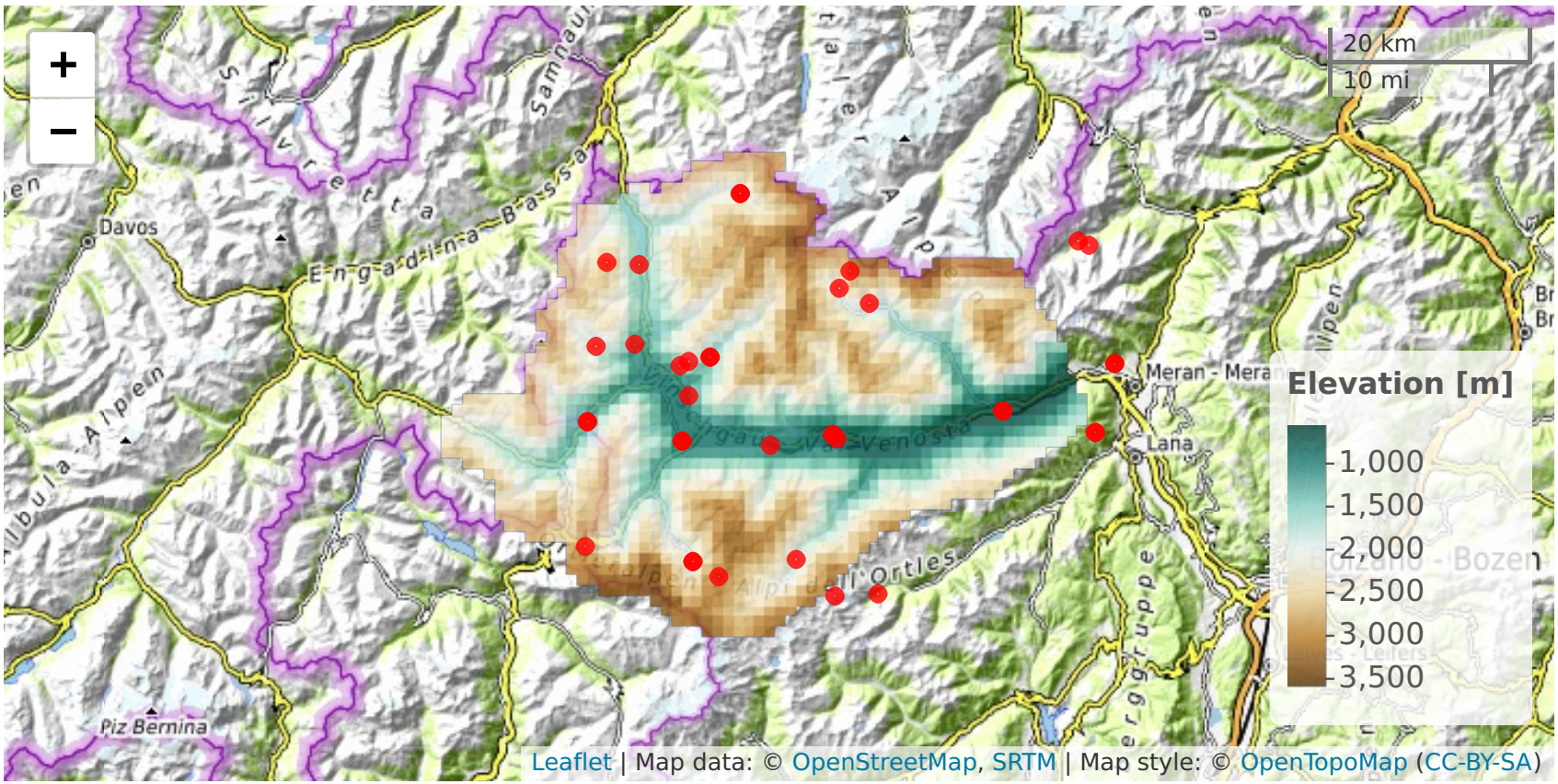


3D Spatially Distributed Distribution: Val Venosta/Vinschgau - Upper Adige River Basin - Alps - I/CH/A

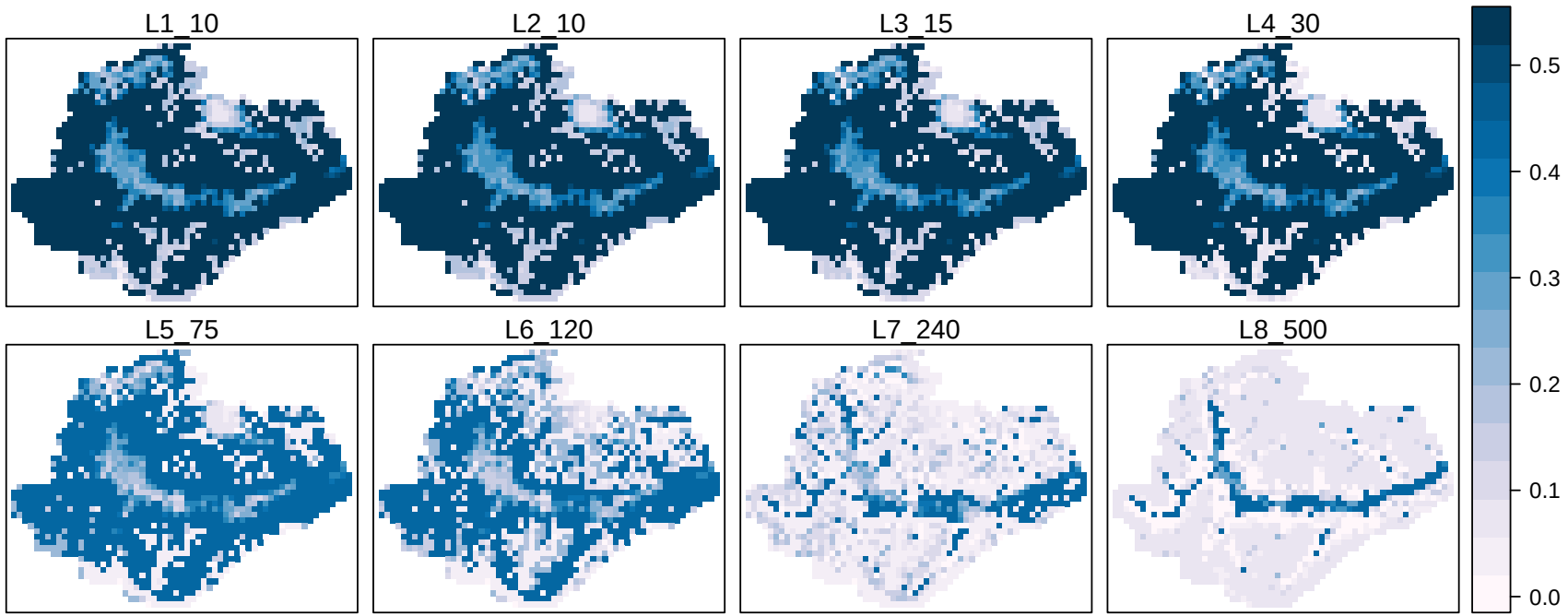
```
wpath_3D <- 'resources/simulation/Vinschgau'
basin <- get.geotop.inpts.keyword.value("LandCoverMapFile",
                wpath=wpath_3D,raster=TRUE)
basin
```

```
## 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

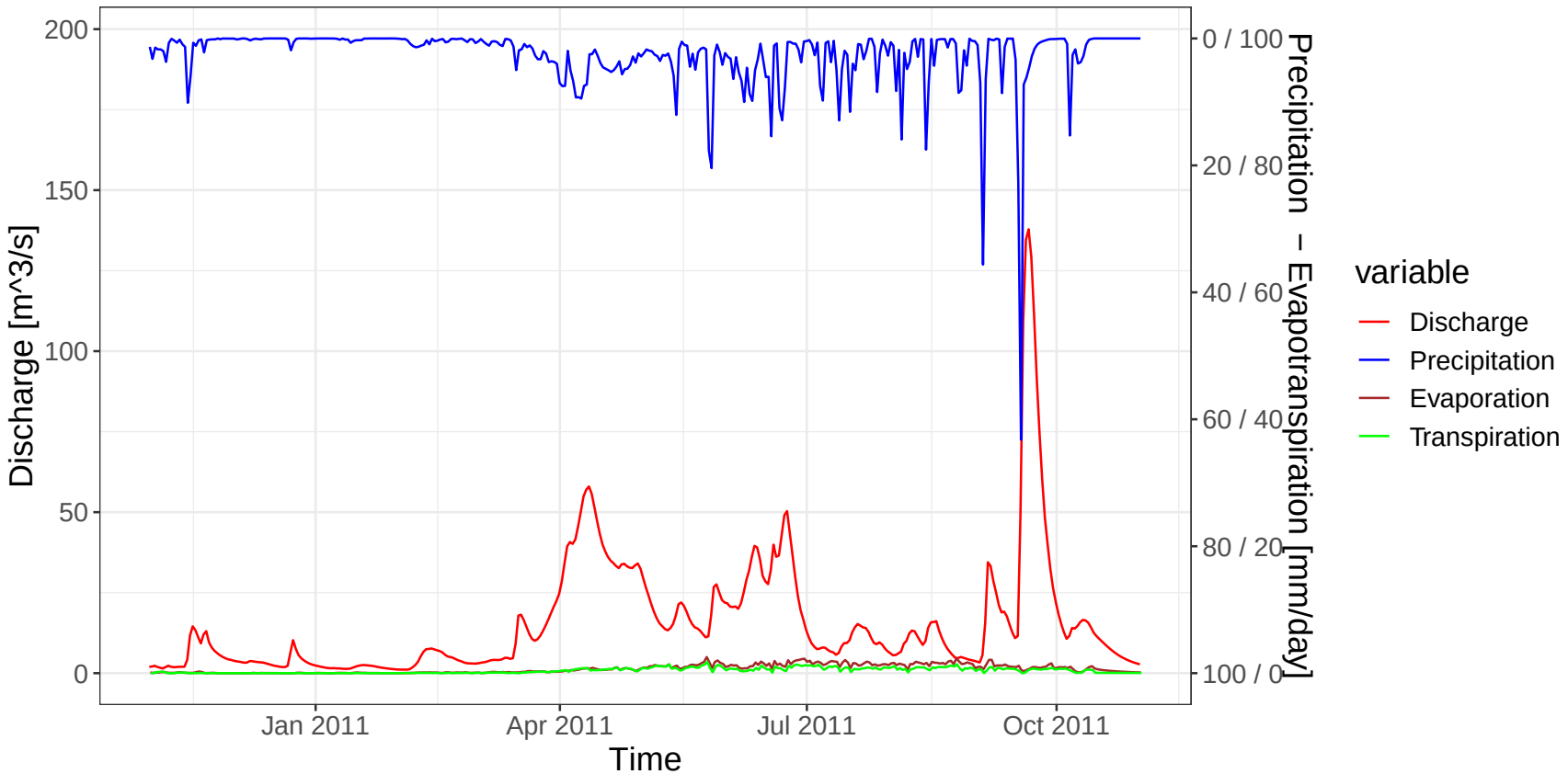


3D Spatially Distributed Simulation (Output Geospatial Map): Soil Water Content




```
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;
- Though **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;
- Open Source (and not only) Hydrolgical Model needs powerful interfaces to process I/O in a FAIR way;
- R code based on **geotopbricks** can help the implantetion of further package or apps: analityics, model calibration, visualization.

Finally

Aknowledgements to

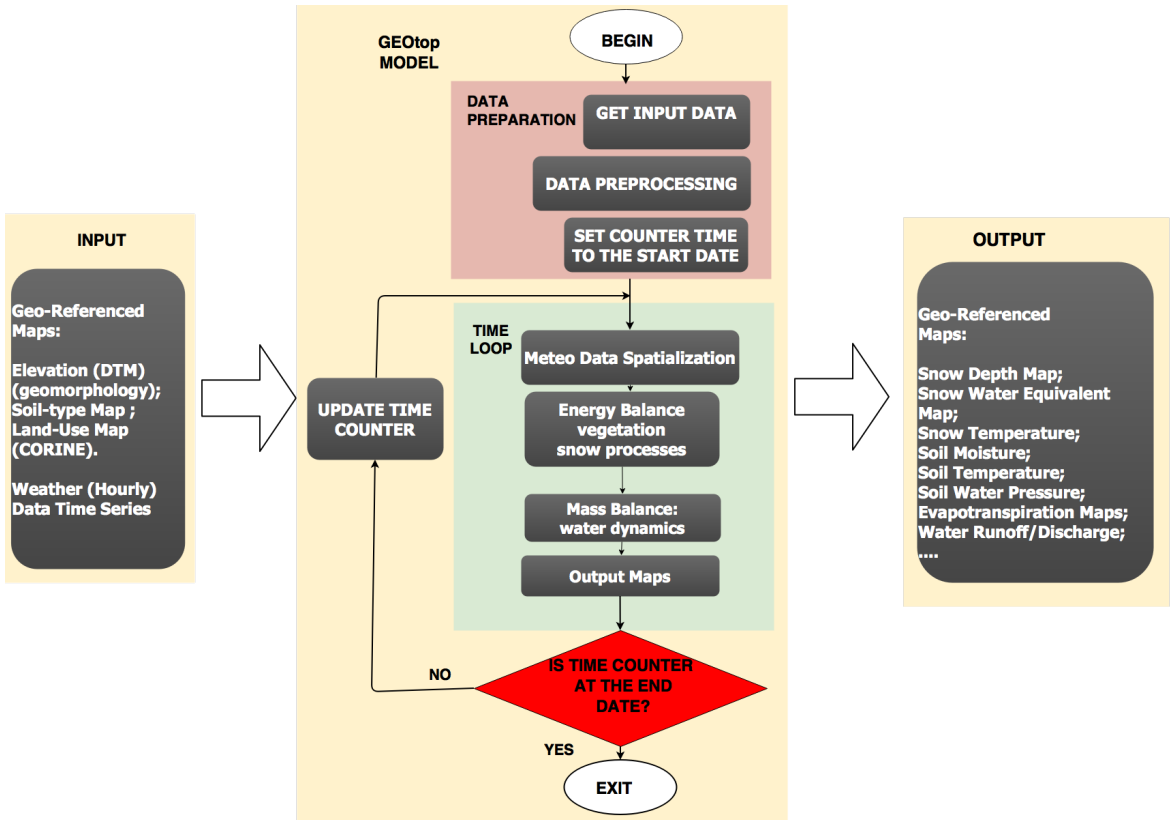
- all **GEOtop** developers and users' group, in particular *Matteo Dall'Amico, Stefano Cozzini, Alberto Sartori, Stefano Endrizzi, Samuel Senoner, Riccardo Rigon*, who provided images about GEOtop and hydrologic models for this presentation
- the community of **R** whose packages allow to analize and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

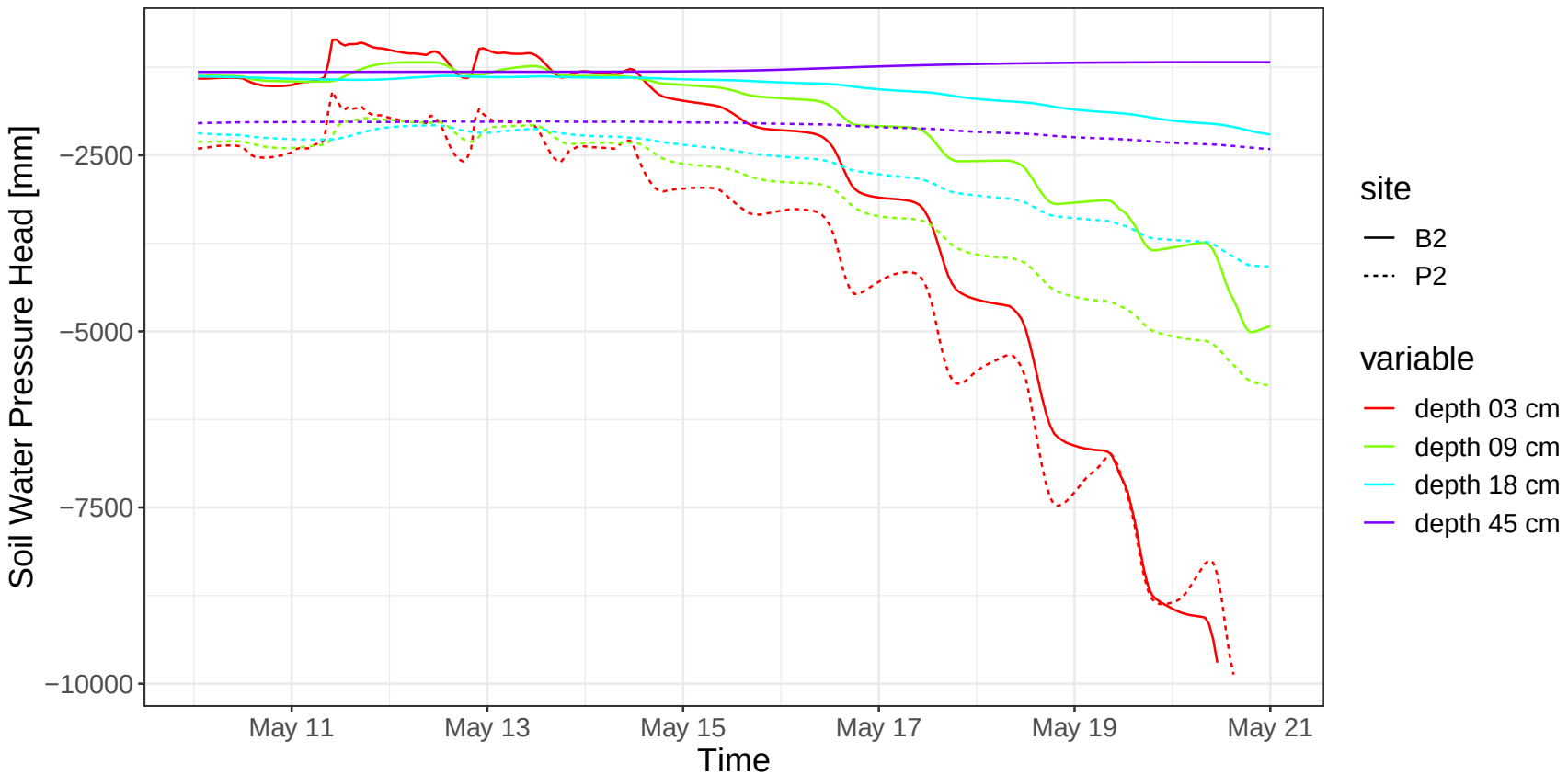
Addendum

GEOtop Hydrological Model Flowchart



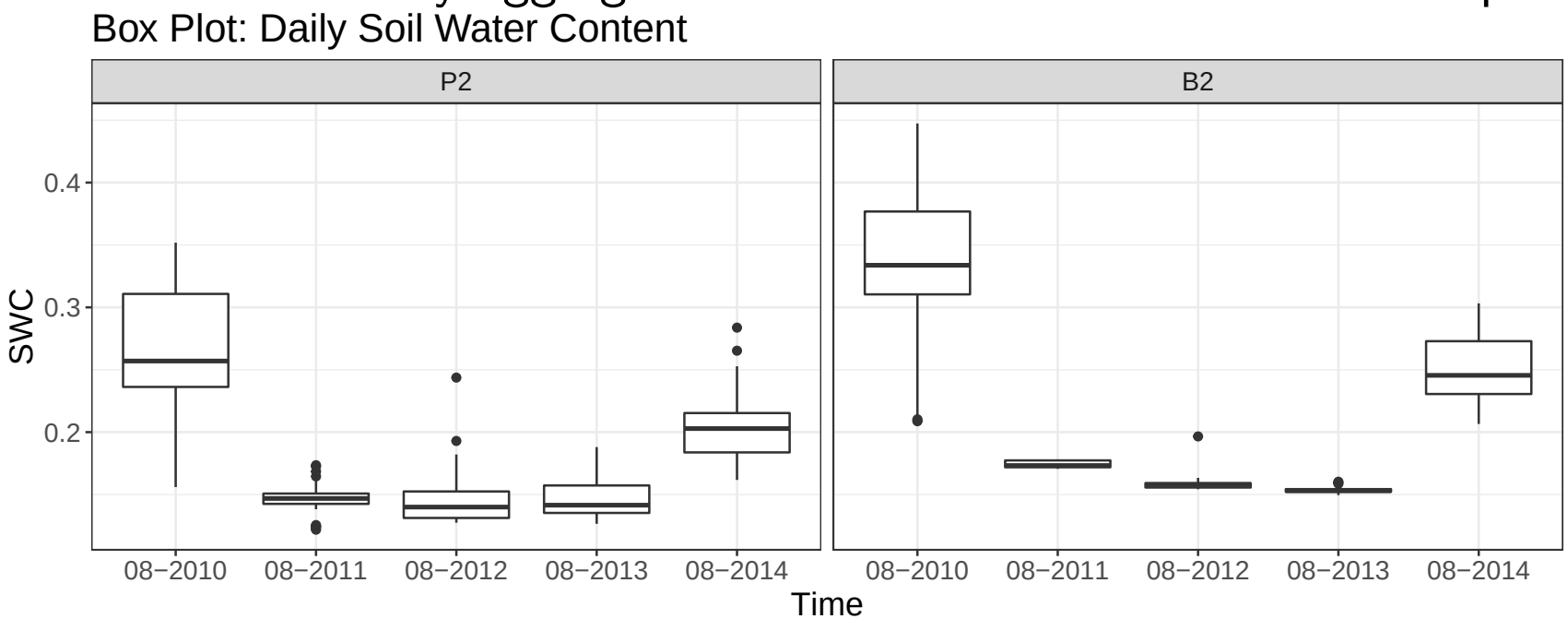
- **Input**: meteo data, elevations, soil parameters,...
- **Output**: snow cover, soil temperature, soil moisture,...

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.