Hydrological Modelling and R

An R Package for the Distributed Hydrological Model GEOtop

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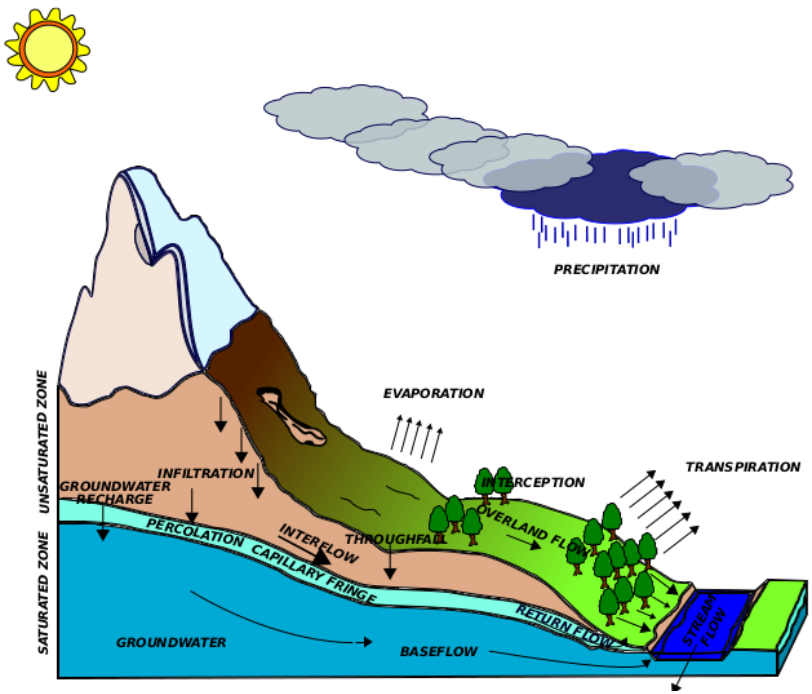
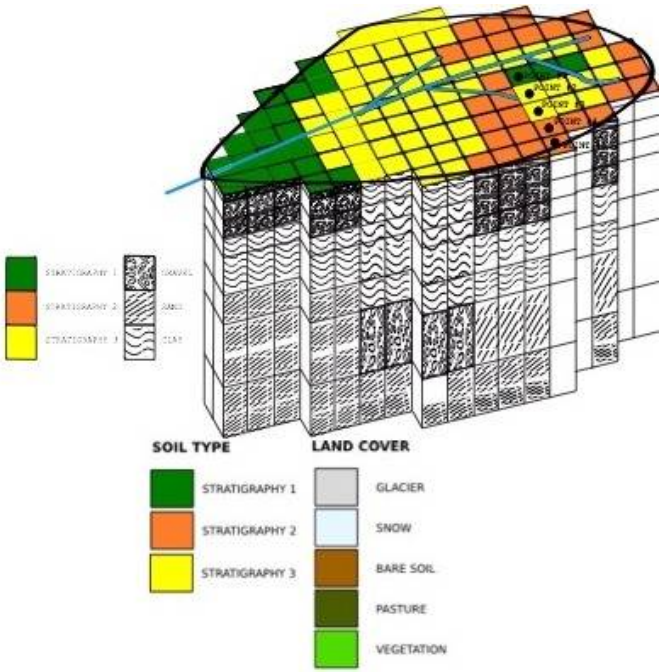
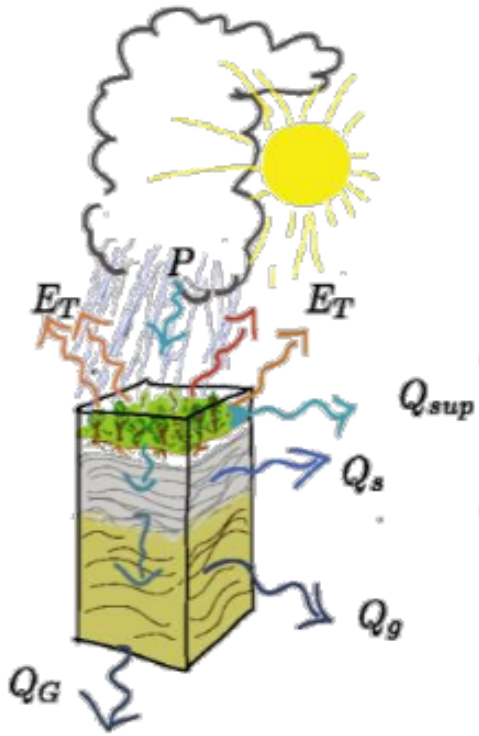
Hydrology

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/geomorpho-logical characterization (*input*).

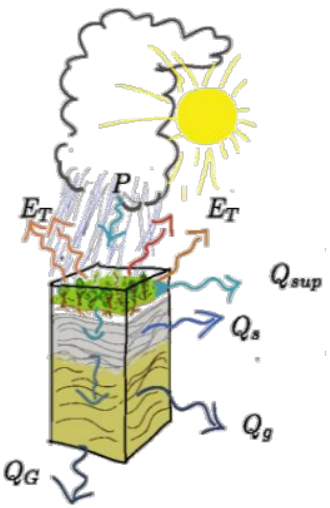
Soil water mass balance equation: $\frac{\partial \theta}{\partial t} = \nabla \cdot [K(\nabla(\psi + z_f))] + S$

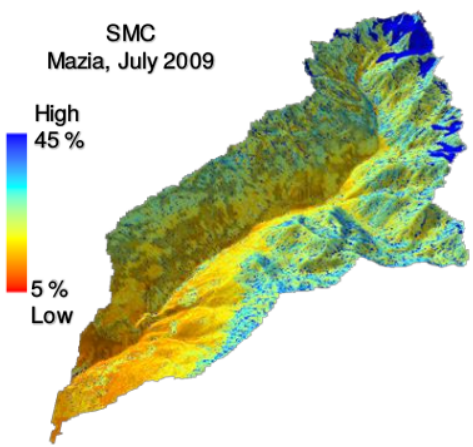
Soil Heat (energy) balance equation: $C_s \frac{\partial T_s}{\partial t} = \nabla \cdot [K_t(\nabla T_s)] + \lambda S$

GEOtop (www.geotop.org)

GEOtop hydrological model is an open-source C/C++ code solveing water and energy balance equations coupled with the exchanges between terrain and lower atmoshere:

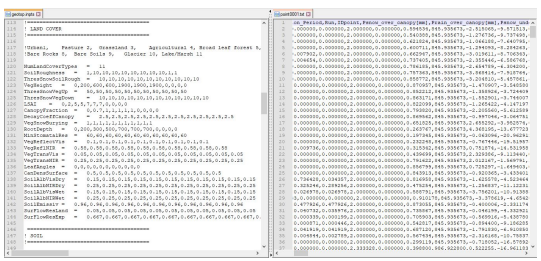
- **1D**: only vertical fluxes $\rightarrow$ balances at local scale (only in one soil column)
- **3D**: vertical and lateral fluxes $\rightarrow$ balances at basin scale





How can we use GEOtop physical variables in R? “geotopbricks” R Package.

GEOtop configuration file, called **geotop.inpts** contains keywords addressing to simulation options (e.g. simulation period) or pointing to **input files** (e.g. meteorological forcings, soil and geomorphology of the basin) or **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 parses **geotop.inpts** and imports **GEOtop** data directly into the *R* session.

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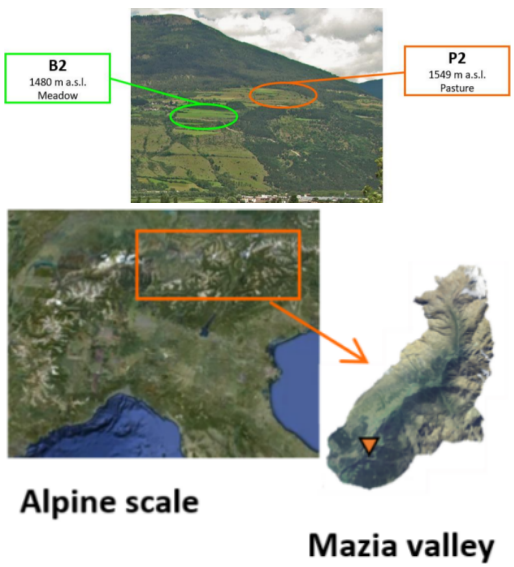
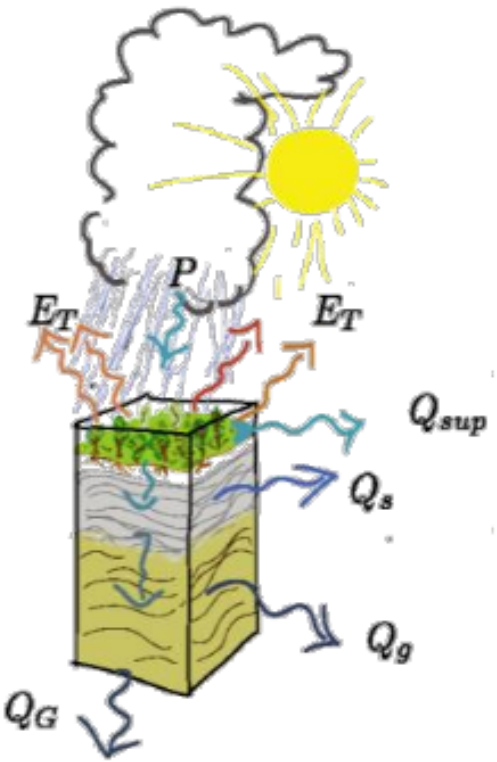
1D GEOtop Simulation in an Alpine Site: 2 Points

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

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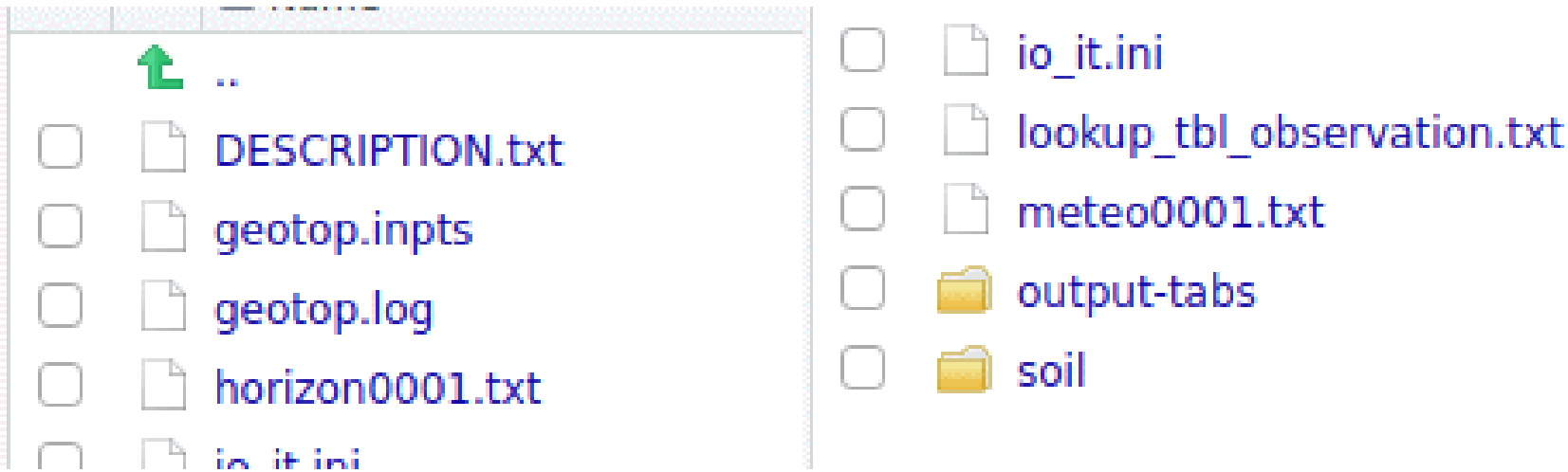
1D GEOtop Simulation in an Alpine Site: B2

Here is the directory containing files of B2 point simulation:

```
library(geotopbricks)

## SET GEOTOP SIMULATION DIRECTORY
wpath_B2 <- "resources/simulation/Matsch_B2_Ref_007"
```



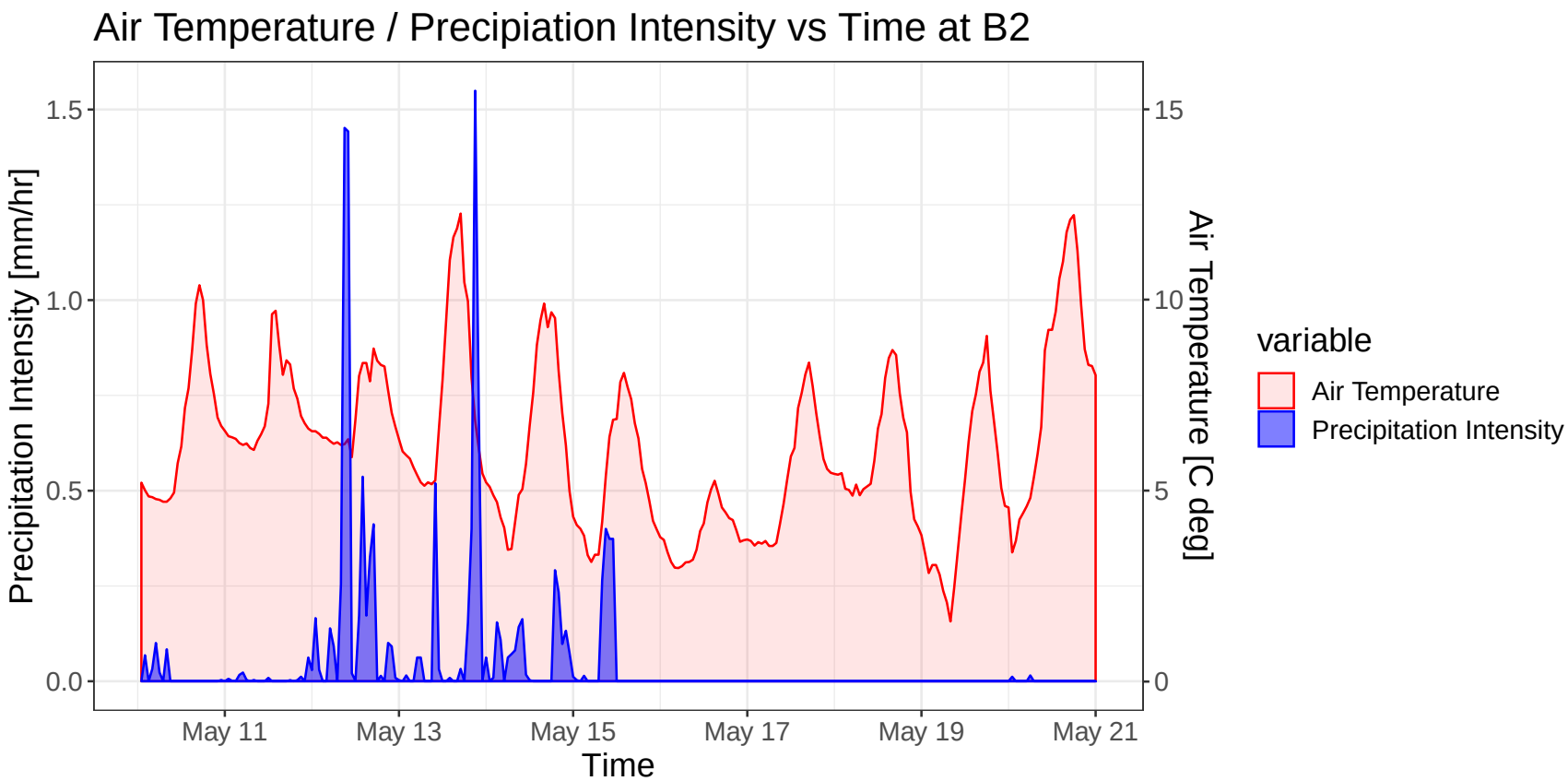
Getting Simulation Input Data

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"
```

Precipitation and Air Temperature at B2



Getting Simulation Output Data

Soil Water Content Profile:

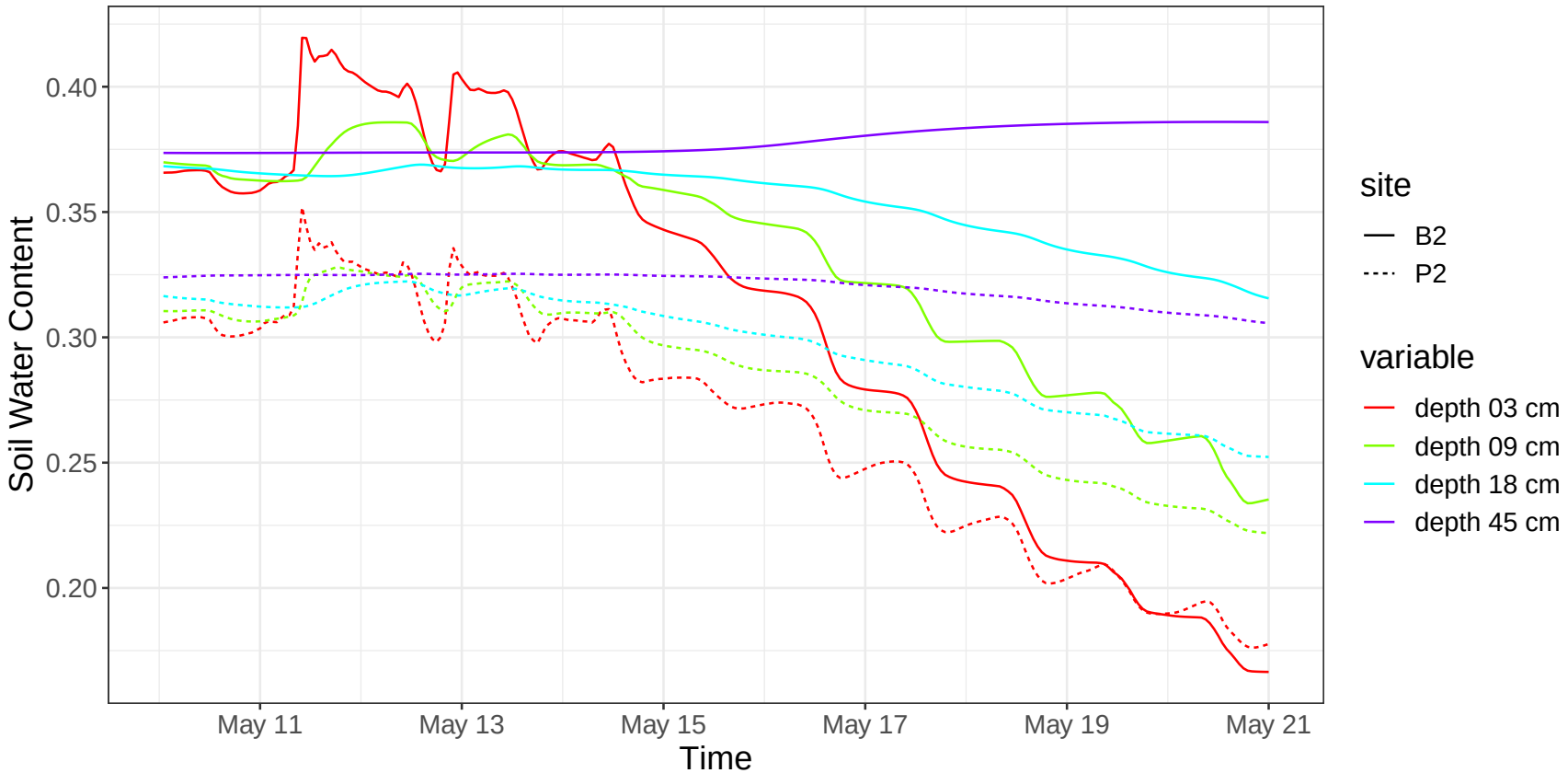
```
tz <- "Etc/GMT-1"
SWC_B2  <- get.geotop.inpts.keyword.value(
  "SoilLiqContentProfileFile",
  wpath = wpath_B2,
  data.frame = TRUE,
  date_field = "Date12.DDMMYYYYhhmm.",
  tz = tz,
  zlayer.formatter = "z%04d"
)
help(get.geotop.inpts.keyword.value) ## for more details!
```

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

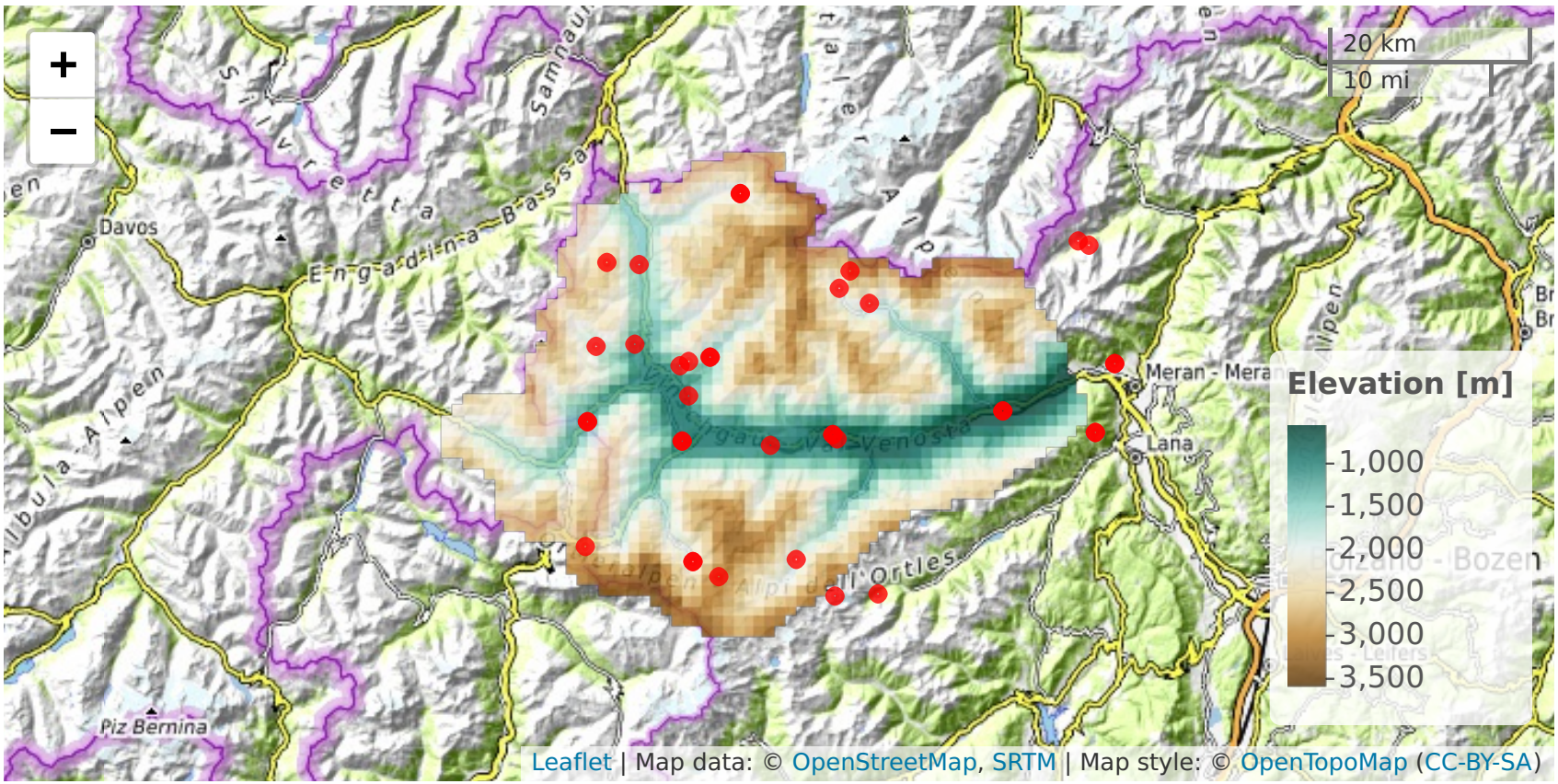


3D Spatially Distributed Simulation: Val Venosta/Vinschgau - Upper Adige River Basin - Alps - I/CH/A

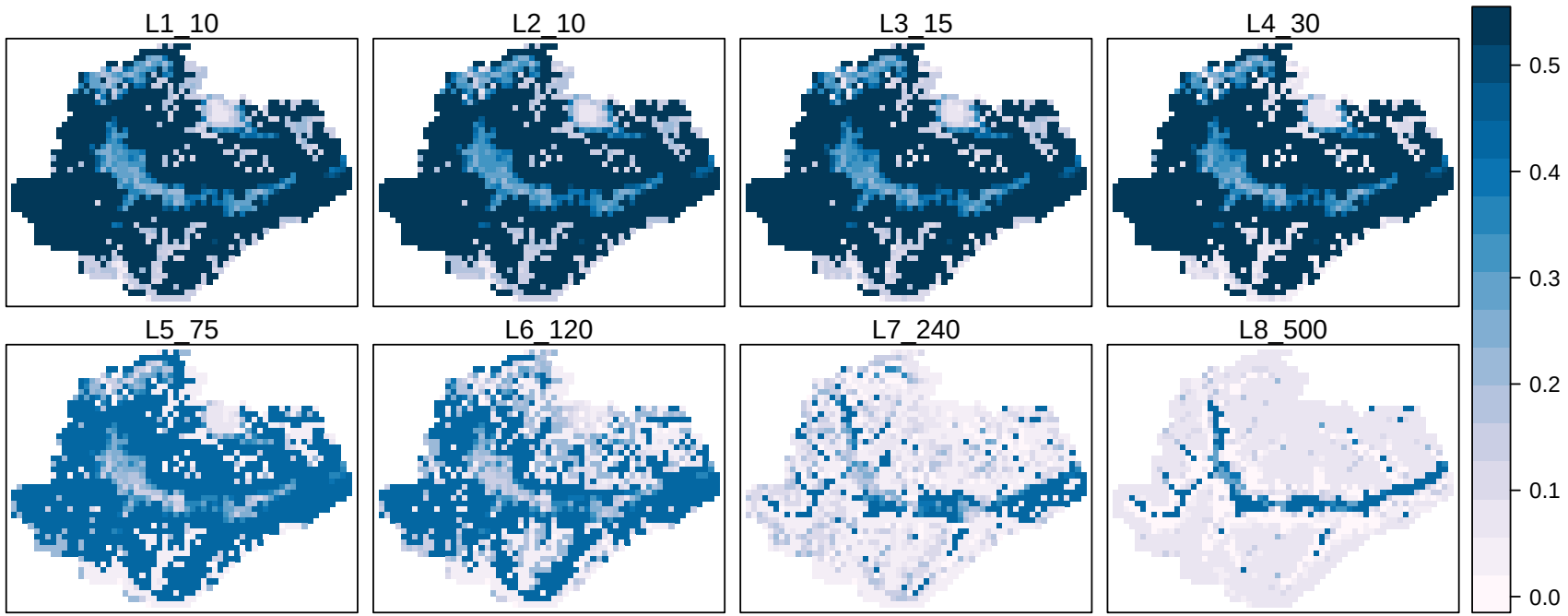
```
wpath_3D <- 'resources/simulation/Vinschgau'
basin <- get.geotop.inpts.keyword.value("LandCoverMapFile",
                wpath=wpath_3D,raster=TRUE)
basin
```

```
## class       : RasterLayer
## dimensions  : 48, 63, 3024  (nrow, ncol, ncell)
## resolution  : 1000, 1000  (x, y)
## extent      : 598000, 661000, 5145000, 5193000  (xmin, xm
## crs         : +proj=utm +zone=32 +ellps=WGS84 +datum=WGS8
## source      : memory
## names       : layer
## values      : 1, 11  (min, max)
```

Input GeoSpatial Map: Elevation and Weather Station

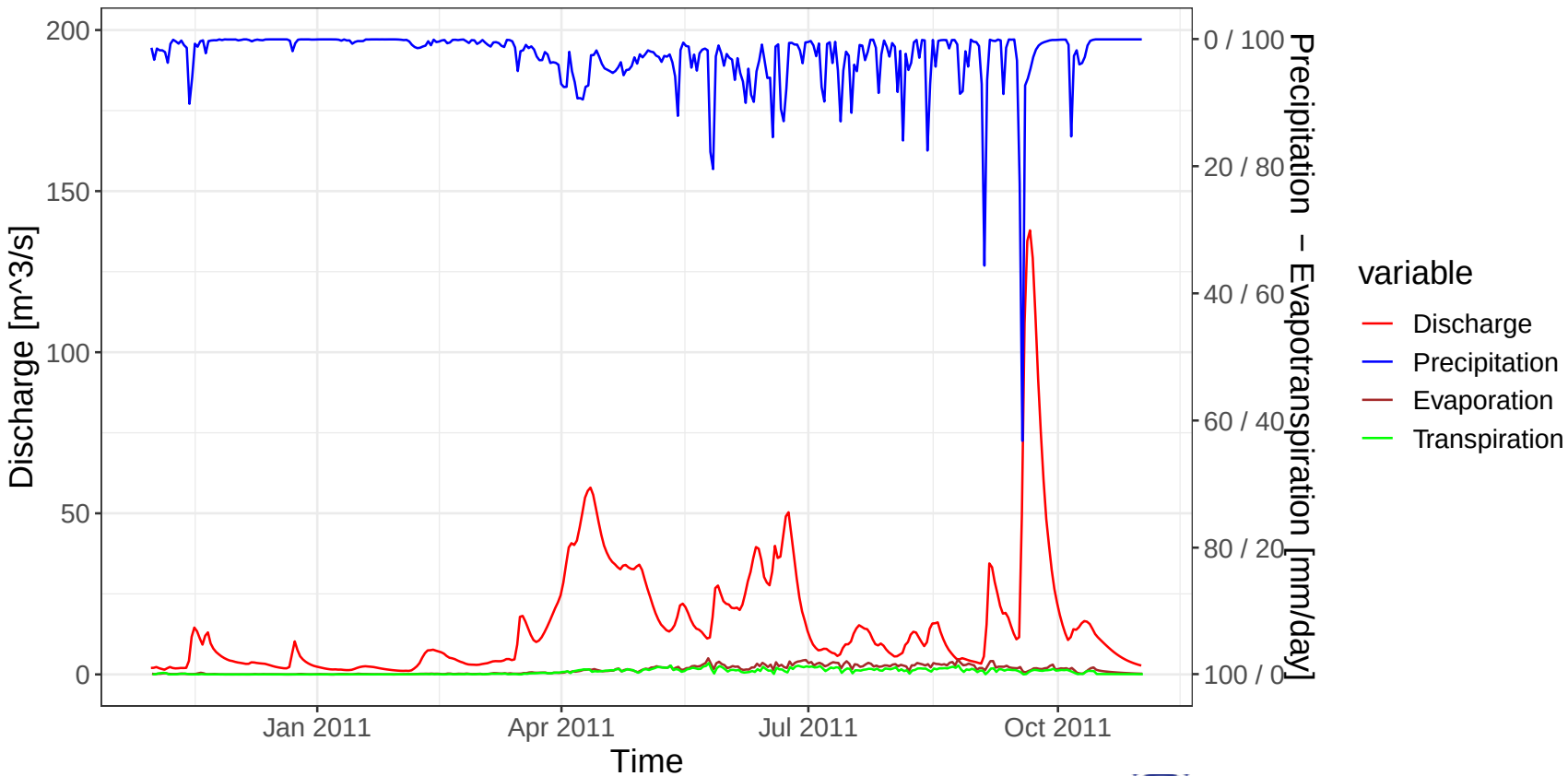


3D Spatially Distributed Simulation (Output Geospatial Map): Soil Water Content



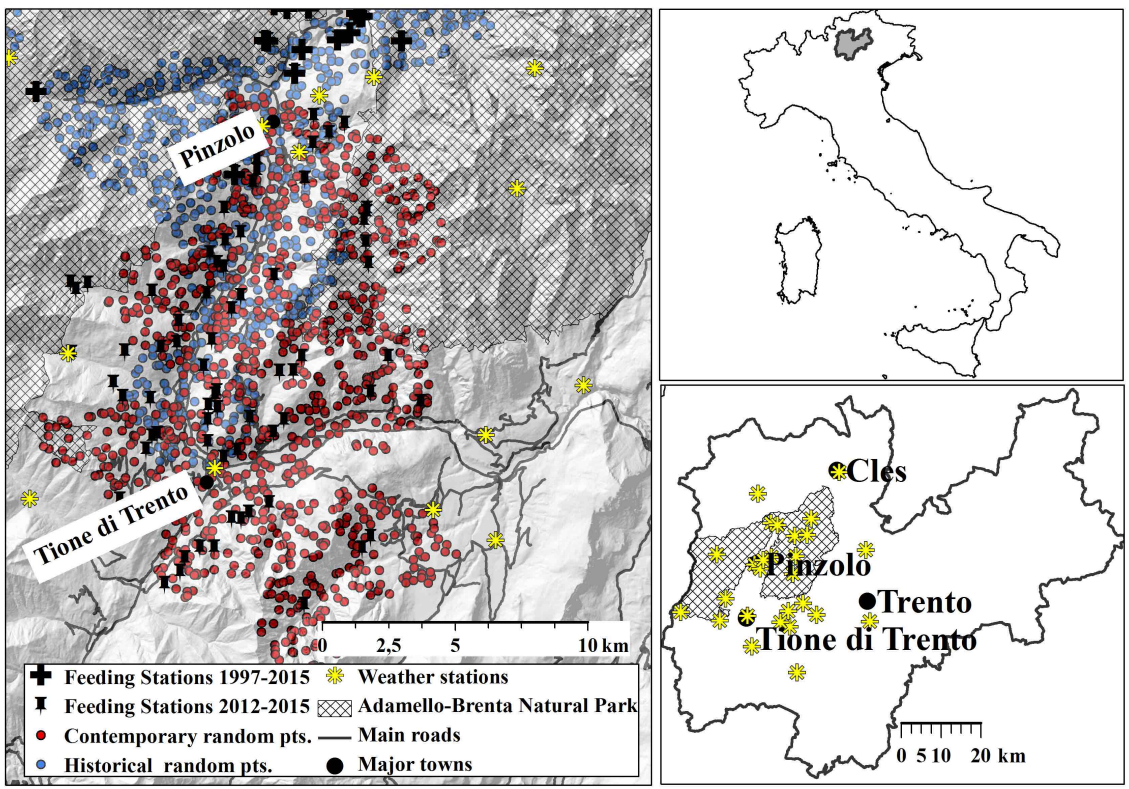

```
brickFromOutputSoil3DTensor("SoilLiqContentTensorFile",
wpath=wpath_3D,when="2011-08-16 12:00:00 +01")
```

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

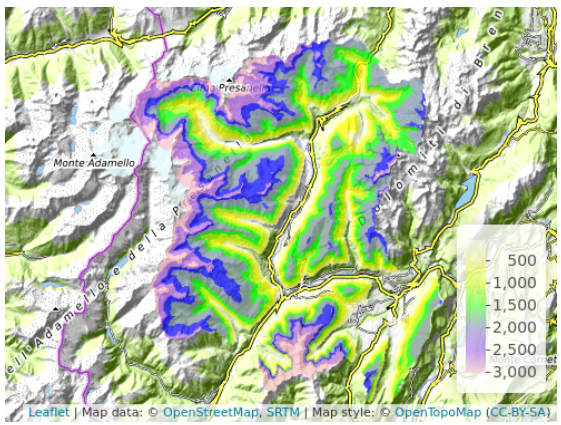
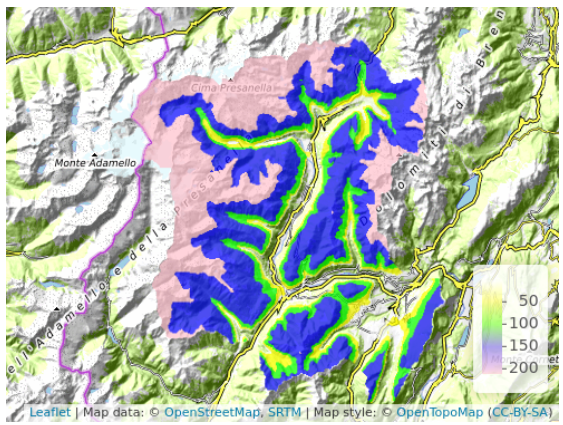
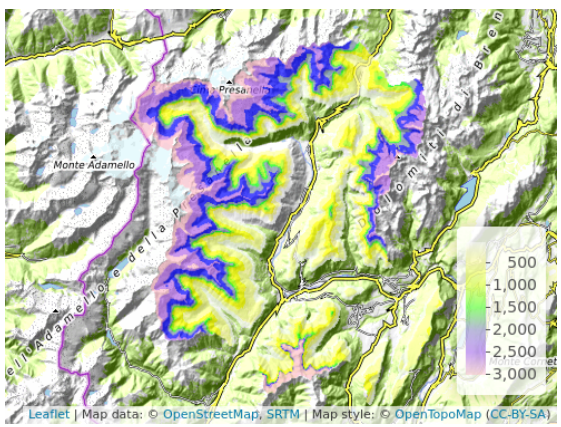
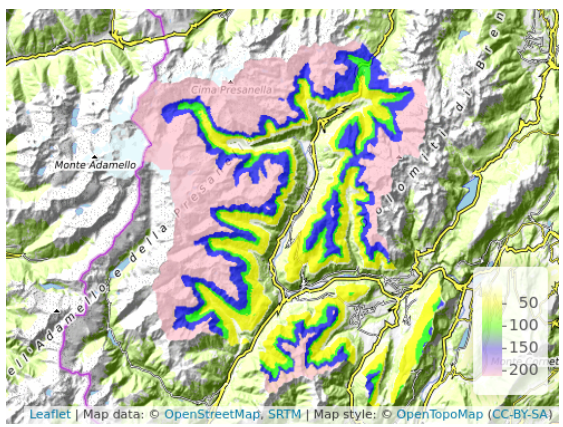


Application: snow cover modelling

Occurrence of large herbivore depending on feeding station location and **snow cover**:

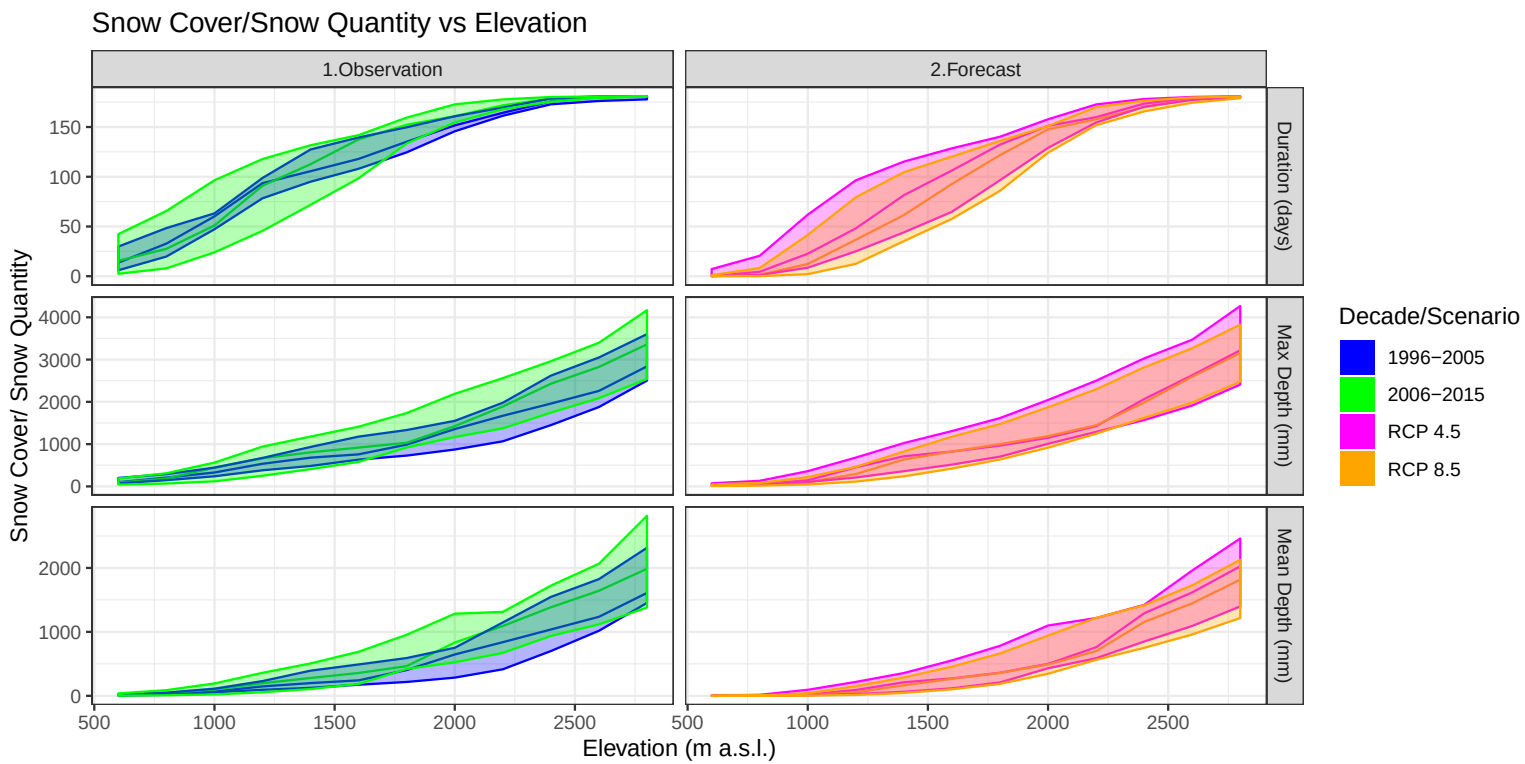


Snow Spatial Distribution in Winter (DJFM)

Winter	Mean Depth [mm]	Duration [days]
2013-2014		
2014-2015		

Snow Depth and Cover Variabilty

Summarize snow depth and snow cover during a winter season versus elevation:



Final Remarks

- **geotopbricks** is an interface of GEOtop in R speaking the language of GEOtop;
- Through **geotopbricks** user can interact between R and GEOtop using R enviroment and GEOtop keywords system, without getting crazy to search files thoughout the specific GEOtop simulation structure;
- This presentation has been created as a **RMarkdown** living and reproducible document, all shown results from GEOtop model have been automatically imported and plotted.

Acknowledgments to GEOtop and R contributors, Thank you for your attention and some tips about us...

Me

Dr. Giacomo Bertoldi

- I'm an Environmental engineer with hydrological background (more deterministic and physically-based than statics!) freelancer, - www.rendena100.eu . I'm author of several R-packages and R enthusiast.
- I work in collaboration with adevanced users and developer of GEOtop hydrologic models with skills in hydrology, environmental science and also in C/C++, parallell programming, High Perfomance Computing, etc.

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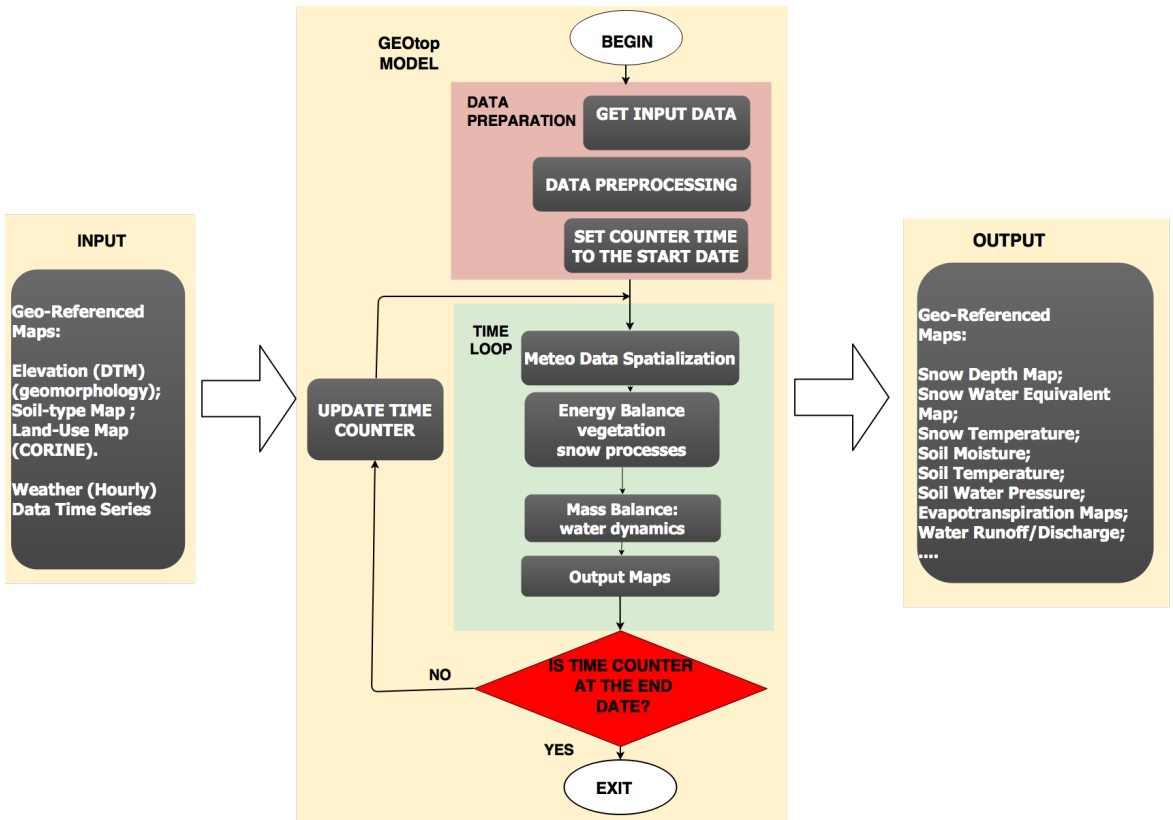
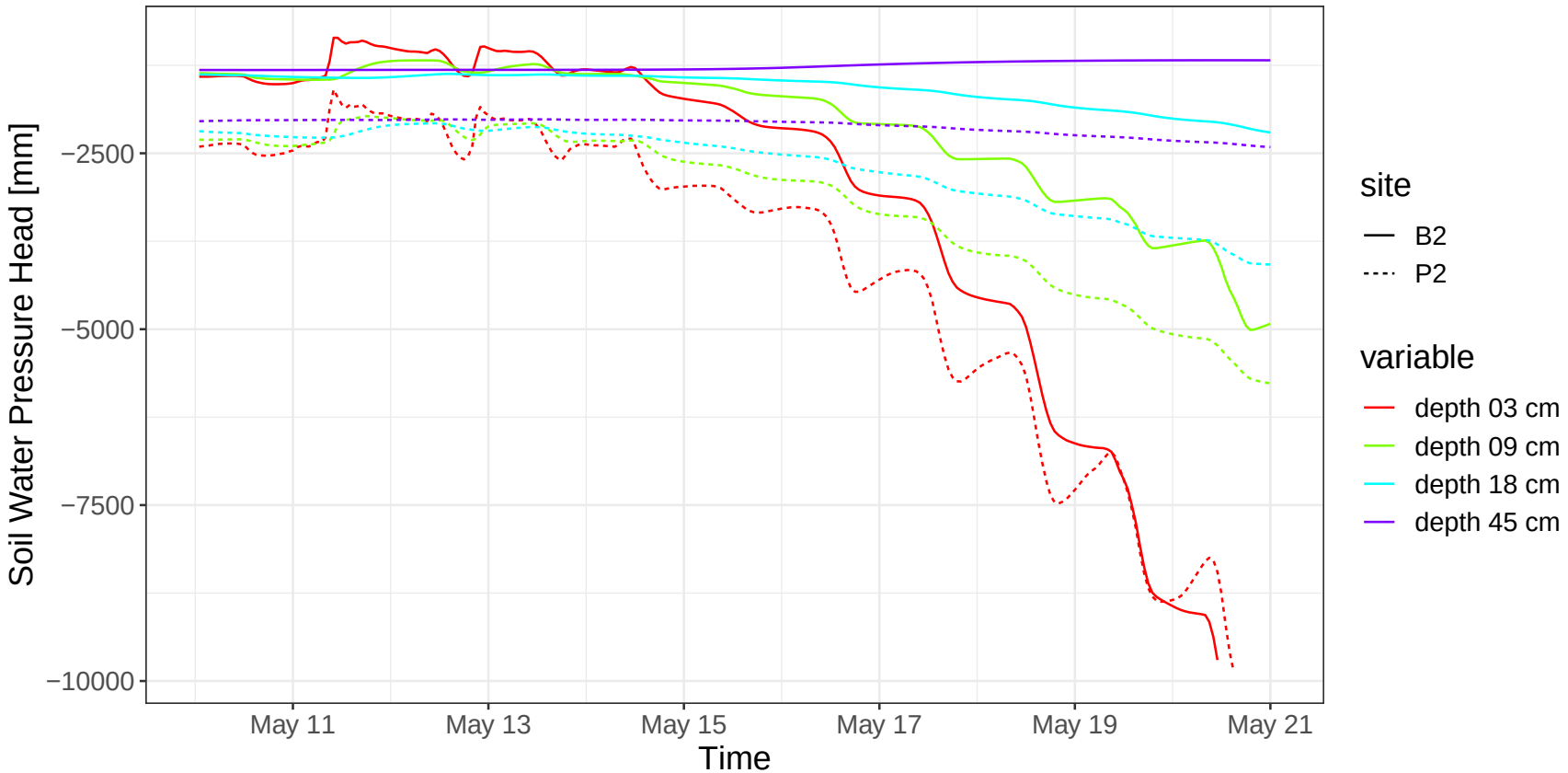
Addendum

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: