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++, 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, evapotranspiration, 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 $\rightarrow$ 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/.

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\textsuperscript{1,2}, Mauro Sulis\textsuperscript{3}, Reed M. Maxwell\textsuperscript{4}, Claudio Paniconi\textsuperscript{5}, Mario Putti\textsuperscript{6}, Giacomo Portoli\textsuperscript{7}, Ethan T. Coon\textsuperscript{8}, Emanuele Cordano\textsuperscript{7,9}, Stefano Endrizzi\textsuperscript{10}, Eugeny Kikinzon\textsuperscript{10},
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 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
EndDateDDMMYYYYhhmmm =01/01/2016 00:00
[...]
MeteoFile ="meteoB2_irr"
PointOutputFile ="tabs/point"
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
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`:

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

```r
## [1] "zoo"
```
Getting Simulation Input Data (verify)

Meteorological time series once imported can be printed:

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

```plaintext
## 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

Air Temperature / Precipitation Intensity vs Time at B2

- Precipitation Intensity [mm/hr]
- Air Temperature [°C]

Time
- May 11
- May 13
- May 15
- May 17
- May 19
- May 21

variable
- Air Temperature
- Precipitation Intensity

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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.DDMYYYhhmm.",
   tz = tz,
   zlayer.formatter = "z%04d"
)

help(get.geotop.inpts.keyword.value) ## for more details!
Getting Simulation Output Data (at P2)

Analogously for P2:

```r
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.DDMMYYYhhm",
    tz = "Etc/GMT-1",
    zlayer.formatter = "z%04d")
```
Soil Water Content at P2 and B2

![Graph showing soil water content over time for sites P2 and B2 at different depths.](graph.png)
3D Spatially Distributed Simulation: Val Venosta/Vinschgau - Upper Adige River Basin - Alps - I/CH/A

```r
code: 

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, xmax, ymin, ymax)
## coord. ref. : +proj=utm +zone=32 +ellps=WGS84 +datum=WGS84 +towgs84=0,0,0
## 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

![Graph showing discharge and variables over time]

- Discharge [$\text{m}^3/\text{s}$]
- Precipitation − Evapotranspiration [mm/day]

Legend:
- Discharge
- Precipitation
- Evaporation
- Transpiration

Time:
- Jan 2011
- Apr 2011
- Jul 2011
- Oct 2011

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**Discussion**

- **geotopbricks** allows graphical representation using R of GEOtop results, useful for hydrologists and researchers;
- Through **geotopbricks** user can interact between R and GEOtop using R environment 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, ...

**Input**
- Geo-Referenced Maps:
  - Elevation (DTM) (geomorphology)
  - Soil-type Map
  - Land-Use Map (CORINE)
- Weather (Hourly) Data Time Series

**Output**
- Geo-Referenced Maps:
  - Snow Depth Map
  - Snow Water Equivalent Map
  - Snow Temperature
  - Soil Moisture
  - Soil Temperature
  - Soil Water Pressure
  - Evapotranspiration Maps
  - Water Runoff/Discharge

**Flowchart**
- Input preparation
- Data preprocessing
- Set counter time to the start date
- Output generation
- Update time counter
- Energy balance
  - Vegetation
  - Snow processes
- Mass balance
  - Water dynamics
- Output maps
- Check time counter
  - Exit if yes
  - Loop if no
Soil Water Pressure Head at P2 and B2

Soil Water Pressure Head [mm]

site
B2
P2

variable
- depth 03 cm
- depth 09 cm
- depth 18 cm
- depth 45 cm

Time
May 11 May 13 May 15 May 17 May 19 May 21

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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.