DRUtES

TUTORIAL: COUPLED HEAT AND WATER – PART 1

November 14, 2017

CONTENTS

LIST OF FIGURES

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1 GOAL AND COMPLEXITY

Complexity: Medium

Prerequisites: None

The goal of this tutorial is to get familiar with the idea of coupled models in 1D. For this we couple the *DRUtES* standard Richards equation module and the heat module. We apply solar radiation data and rain and evaporation data as input.

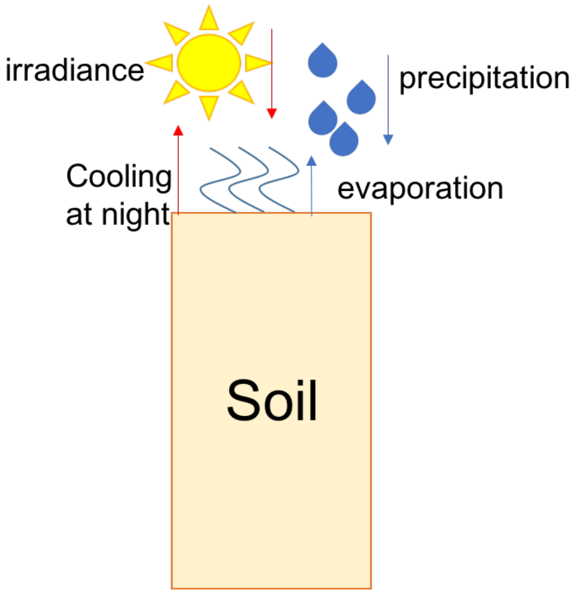

Figure 1: Simplified scheme of coupled model.

In the real world many coupled processes occur. Heat conduction is dependent on the water content and water flow is dependent on heat properties.

In this tutorial three configuration files will be modified step by step. All configuration files are located in the folder *drutes.conf* and respective subfolders.

1. For selection of the module, dimension and time information we require *global.conf*. *global.conf* is located in *drutes.conf / global.conf*.

2. To define the mesh or spatial discretization in 1D, we require *drumesh1D.conf*. *drumesh1D.conf* is located in *drutes.conf / mesh / drumesh1D.conf*.

3. To define the radiation and cooling, we require *matrix.conf*. *matrix.conf* is located in *drutes.conf /water.conf/ matrix.conf*.

4. To define the precipitation and evaporation, we require *matrix.conf*. *matrix.conf* is located in *drutes.conf /water.conf/ matrix.conf*.

DRUtES works with configuration input file with the file extension .conf. Blank lines and lines starting with # are ignored. The input mentioned in this tutorial therefore needs to be placed one line below the mentioned keyword, unless stated otherwise.

2 SOFTWARE

1. Install *DRUtES*. You can get *DRUtES* from the github repository drutes-dev or download it from the drutes.org website.

2. Follow website instructions on drutes.org for the installation.

3. Working R installation (optional, to generate plots you can execute freely distributed R script)

3 SCENARIOS

We are using the well-known van Genuchten-Mualem parameterization to describe the soil hydraulic properties of our soils.

Table 1: Material properties needed for scenarios.

Parameter	Description	Soil
α [cm^{-1}]	inverse of the air entry value	0.05
n [-]	shape parameter	2
m [-]	shape parameter	0.5
θ_s [-]	saturated vol. water content	0.45
θ_r [-]	residual vol. water content	0.05
Ss [cm^{-1}]	specific storage	0
K_s [cm d^{-1}]	saturated hydraulic conductivity	100
c_l [Wd cm^{-3} K^{-1}]	specific heat capacity of soil	2.545e-5
c_w [Wd cm^{-3} K^{-1}]	specific heat capacity of water	4.843e-5
λ [W cm^{-1} K^{-1}]	thermal conductivity	0.02

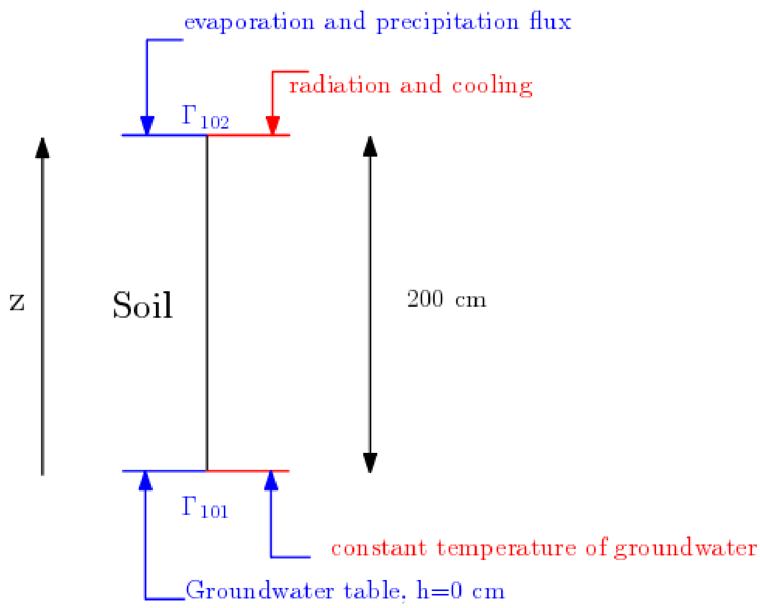

Figure 2: 1D domain set-up of coupled scenario with top and bottom boundary conditions. There are now two boundary condtions at the top and two boundary conditions at the bottom: heat and water flow. The top boundary is defined by the interactions with the atmosphere and the bottom boundary is defined by the constant groundwater table.

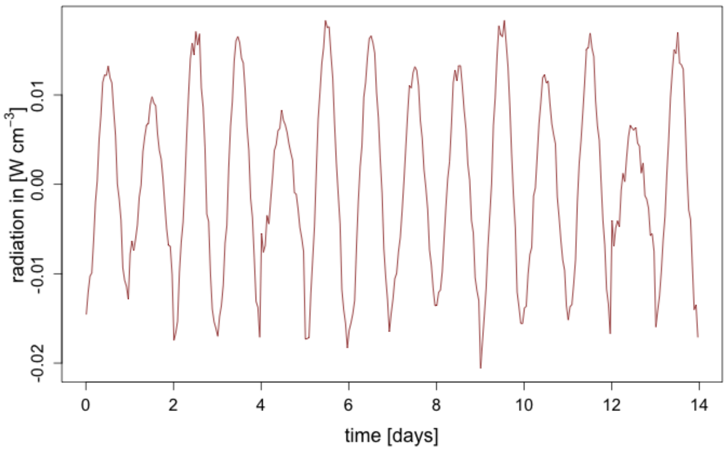

Figure 3: Heat flow data used for the top boundary

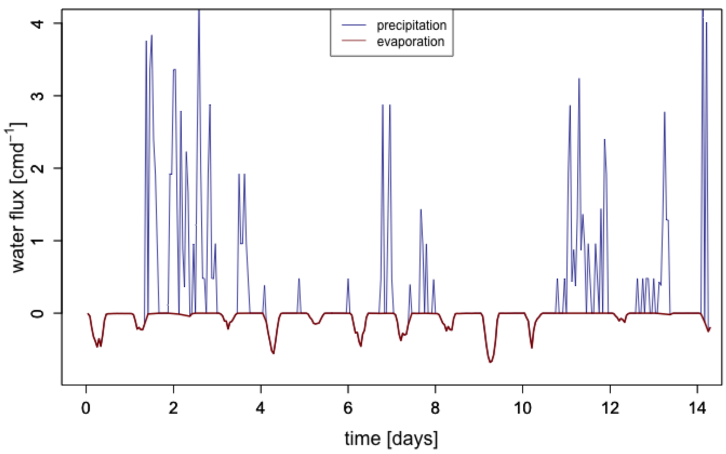

Figure 4: Water flow data used for the top boundary

SCENARIO 1

Coupled model

global.conf: Choose correct model, dimension, time discretization and observation times.

1. Open ***global.conf*** in a text editor of your choice.
2. Model type: Your first input is the module. Input is **RE**.
3. Initial mesh configuration
   a) The dimension of our problem is 1. Input: 1.
   b) We use the internal mesh generator. Input: 1.
4. Error criterion
   a) Maximum number of iteration of the Picard method: 20
   b) h tolerance: 1.

5. Time information
   a) Time units are in hours: input d
   b) Initial time: 1e-6.
   c) End time: 24.
   d) Minimum time step: 1e-6.
   e) Maximum time step: 0.001.
6. Observation time settings
   a) Observation time method: 2
   b) Set file format of observation: pure. Output in 1D is always in raw data. Different options will not impact output in 1D.
   c) Make sequence of observation time: n
   d) Number of observation times: 0
   e) Observation time values: #
7. Observation point settings
   a) Number of observation points: 6
   b) Observation point coordinates: 200, 195,180,160,140, 120. Use a new line for each input. *DRUtES* will generate 6 output files, e.g. *obspt_RE_matrix-1.out*, where x is the ID of the observation point.
8. Ignore other settings for now.
9. Save *global.conf*

drumesh1D.conf: Mesh definition, i.e. number of materials and spatial discretization

1. Open ***drumesh1D.conf*** in a text editor of your choice.
2. Geometry information: 200 cm - domain length
3. Amount of intervals: 1
4.

density	bottom	top
4	0	200

5. number of materials: 1
6.

id	bottom	top
1	0	200

matrix.conf: Configuration file for water flow

1. Open *matrix.conf* in a text editor of your choice.
2. How-to use constitutive relations? [integer]: 1
3. Length of interval for precalculating the constitutive functions: 200
4. Discretization step for constituitive function precalculation: 0.1
5. number of soil layers [integer]: 1
6.

alpha	n	m	theta_r	theta_s	specific storage
0.05	2	0.5	0.05	0.45	0

7. The angle of the anisotropy determines the angle of the reference coordinate system. 0 means vertical flow. Anisotropy description. Anisotpropy description and hydraulic conductivity

angle [degrees]	K_11
0	100

8. sink(-) /source (+) term per layer: 0
9. Initial condition is a constant pressure head of -200 cm across the soil.

init. cond [real]	type of init. cond	RCZA method [y/n]	RCZA method val.
0.0	H_tot	n	0

10. number of boundaries: 2
11.

boundary ID	boundary type	use rain.dat [y/n]	value
101	1	n	0.0
102	2	y	0.0

12. Save matrix.conf.

heat.conf: Heat module after Sophocleous (1979).

1. Open *heat.conf* in a text editor of your choice.
2. Couple with Richards equation: y
3. Number of materials or layers: 1
4. Specific heat capacity of the wall material: 2.545e-5 Wd cm^{-3} K^{-1}
5. Specific heat capacity of liquid: 4.843e-5 Wd cm^{-3} K^{-1}
6. Anisotropy: There is no anisotropy. The value is 0.
7. Heat conductivity of the wall material: 1.7 W m^{-1} K^{-1}.
8. There is NO heat convection of water: 0.
9. The initial temperature is 0°C across the entire domain: 0.
10. There is no heat source: 0.
11. We have 2 boundaries at top and bottom of the soil column. We assume a constant temperature of 15 °C at the bottom where the groundwater table is. We assume the the top to be influenced by radiation and cooling, which are both flux or Neumann conditions.

boundary id	boundary type	use bc.dat	value
101	1	n	15.0
102	2	y	0.0

12. Save heat.conf.

RUN SCENARIO 1

Run the simulation in the terminal console.

1. Make sure you are in the right directory.
2. To execute *DRUtES*:
   $ bin/drutes

3. After the simulation finishes, to generate png plots execute provided R script:
   $ Rscript drutes.conf/water.conf/waterplots.R -name coupled
   $ Rscript drutes.conf/heat.conf/heatplots.R coupled

4. The output of the simulation can be found in the folder out

TASKS

1. Describe the temperature and water content distribution.

RESULTS

The water content at the top follows the flux input. The lower the observation point, the less fluctuations can be observed. The temperature follows the heat flux input. The temperature fluctuations become smaller with depth, but also show a lag time.

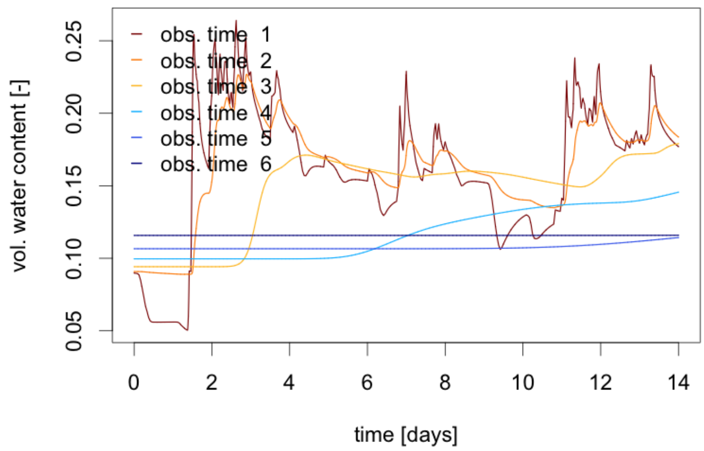

Figure 5: Water content at the observation points

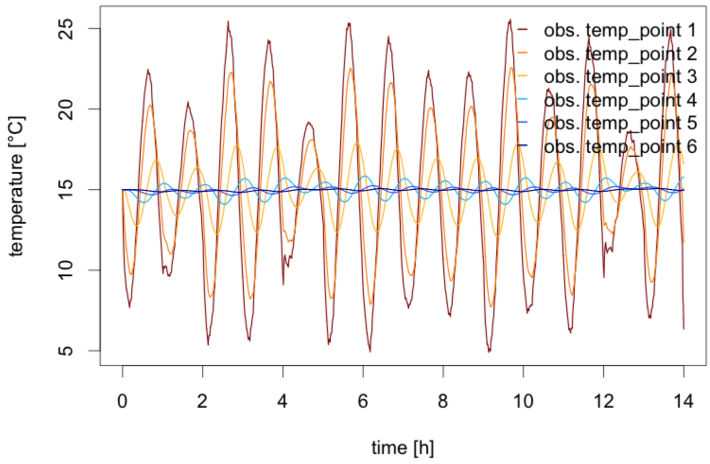

Figure 6: Temperature at the observation points.

4 OUTCOME

1. You got familiar with the idea of coupled models.
2. You simulated coupled water flow and heat flow.
3. You understand the influence of distance to input flux and how the top is the most varying layer.