Comparison of Simple and Sperry regulation models

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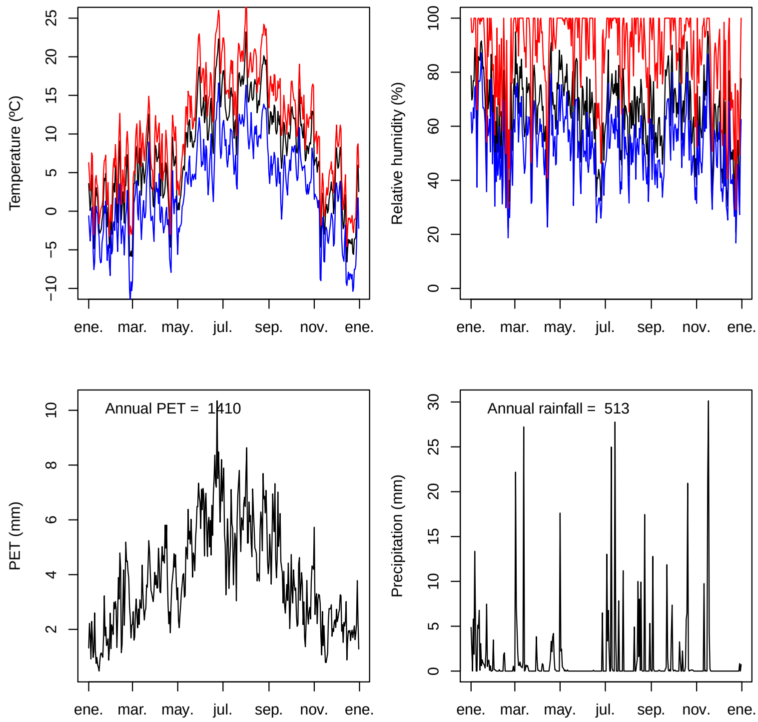
1 Preliminaries

The aim of this study is to evaluate the agreement and differences between the transpiration regulation modes, here called 'Simple' and 'Sperry'. Using daily simulations encompassing one year, we study differences in plant transpiration, flow from different soil layers and plant/soil water potentials.

1.1 Climate data

We took the climatic example data set of the package, covering one year. We limit minimum wind speed to 3 m/s, as the Sperry regulation model is highly sensitive to low values of wind speed [and I suspect that Penman approach to PET assumes a minimum amount of wind]. The daily weather that will force our soil moisture and transpiration dynamics is:



1.2 Soil and forest data

In this study the soil only has two layers only (0-300, 300-1000 mm), and we set rock fragment content to 30% and 60%, resulting in in a water holding capacity of 149 mm:

```
> sp = defaultSoilParams(2)
> sp$rfc=c(30,60)
> soil(sp)

Soil depth (mm): 1000

Layer  1  [ 0  to  300 mm ]
    clay (%): 25 silt (%): 50 sand (%): 25 organic matter (%): NA [ Silt loam ]
    Rock fragment content (%): 30 Macroporosity (%): 10
    Theta FC (%): 30 Vol. FC (mm): 64 Vol. current (mm): 64

Layer  2  [ 300  to  1000 mm ]
    clay (%): 25 silt (%): 50 sand (%): 25 organic matter (%): NA [ Silt loam ]
    Rock fragment content (%): 60 Macroporosity (%): 10
    Theta FC (%): 30 Vol. FC (mm): 85 Vol. current (mm): 85
```

```
Total soil water holding capacity (mm): 149

Total current Volume (mm): 149
```

We consider two different forest stands. The first contains a single tree cohort:

```
> forest1 = exampleforest
> forest1$treeData = forest1$treeData[1,]
> forest1$treeData$N = forest1$treeData$N*4
> forest1$shrubData = forest1$shrubData[-(1:4),]
> forest1$treeData$Z50 = 200
> forest1$treeData$Z95 = 1000
> forest1$treeData

  Species   N   DBH Height Z50  Z95
1      54 672 37.55    800 200 1000

> summary(forest1, SpParamsMED)

Forest summary:

  Tree density (ind/ha): 672
  BA (m2/ha): 74.4181869
  Shrub crown phytovolume (m3/m2): 0
  LAI (m2/m2) total: 1.6297739  trees: 1.6297739  shrubs: 0
  Live fine fuel (kg/m2) total: 0.8113645  trees: 0.8113645  shrubs: 0
```

The second contains two cohorts of the same species, differing only in height and diameter:

```
> forest2 = forest1
> forest2$treeData = as.data.frame(rbind(forest2$treeData, forest2$treeData))
> forest2$treeData$N = forest2$treeData$N/2
> forest2$treeData$Height[2] = forest2$treeData$Height[1]/2
> forest2$treeData$DBH[2] = forest2$treeData$DBH[1]/1.3
> forest2$treeData

  Species   N      DBH Height Z50  Z95
1      54 336 37.55000    800 200 1000
2      54 336 28.88462    400 200 1000

> summary(forest2, SpParamsMED)

Forest summary:
```

```
Tree density (ind/ha): 672
BA (m2/ha): 59.2263085
Shrub crown phytovolume (m3/m2): 0
LAI (m2/m2) total: 1.7106903  trees: 1.7106903  shrubs: 0
Live fine fuel (kg/m2) total: 0.8516479  trees: 0.8516479  shrubs: 0
```

The proportion of fine roots in each layer is:

```
> root.ldrDistribution(200,1000,c(300,700))

          [,1]      [,2]
[1,] 0.7129407 0.2870593
```

2 Simulations with constant soil moisture

2.1 One cohort

In this set of simulations we assumed that soil was always at full capacity. Two parameters, xylem conductivity and maximum carboxilation rate at 25ºC, have been previously optimized to this situation (i.e. least squares optimization of daily total transpiration), which gave the following values:

```
> SpParamsMED$xylem_kmax =  2.0 #0.1089123
> SpParamsMED$Vmax298=100
```

We initialize soil objects and the input to soil water balance simulation routines:

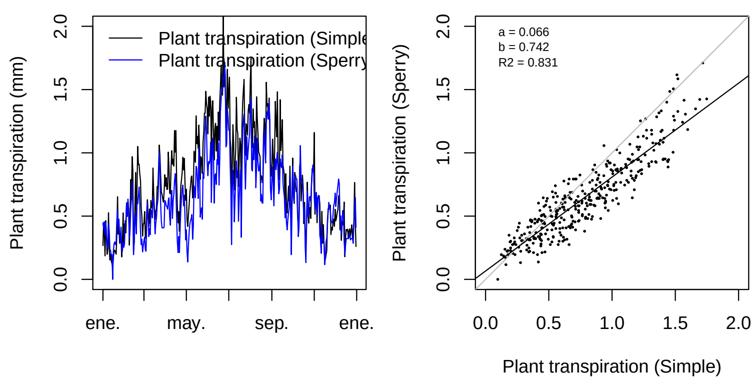
```
> examplesoil1 = soil(sp)
> examplesoil2 = soil(sp)
> control = defaultControl()
> control$verbose = FALSE
> control$transpirationMode="Simple"
> x1 = forest2swbInput(forest1,examplesoil1, SpParamsMED, control)
> control$transpirationMode="Complex"
> control$canopyMode="sunshade"
> x2 = forest2swbInput(forest1,examplesoil2, SpParamsMED, control)
```

Transpiration and below-ground parameters for the two regulation modes are the following:

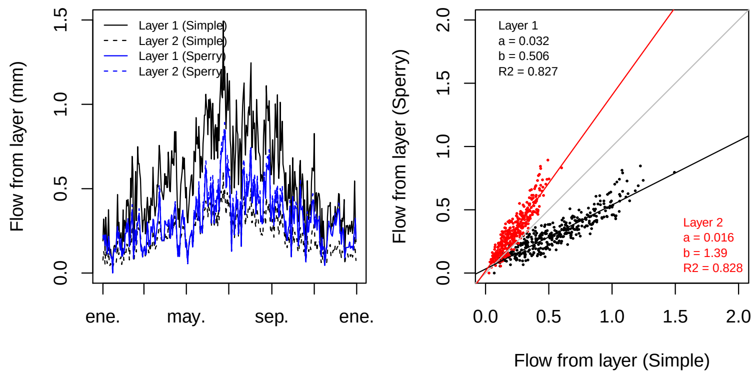
```
> x1$paramsTransp

      Psi_Extract WUE pRootDisc
T1_54          -2   6         0

> x1$below
```

```
$V
                1          2
T1_54 0.7129407 0.2870593

> x2$paramsTransp

      Gwmin Gwmax Vmax298  Jmax298 VCroot_c VCroot_d xylem_kmax
T1_54 1e-05   0.6     100 163.6253        3       -2          2
      VCstem_kmax VCstem_c VCstem_d pRootDisc
T1_54    1.736111        3       -2         0

> x2$below

$V
                1          2
T1_54 0.7129407 0.2870593

$VGrhizo_kmax
                 1          2
T1_54 2327109926 936990365

$VCroot_kmax
               1        2
T1_54 1.391514 1.502004
```

We simulated transpiration day-by-day on `forest1`, using both regulation models, and reinitializing soil each time (code not shown), so that soil water deficit does not affect the comparison of results. We found a very good agreement between the predicted transpiration under the two regulation modes. This agreement is an important step for the verification of the more Sperry regulation model. However, we have to remember that maximum stem conductivity and maximum carboxylation rate have been optimized to maximize this agreement:

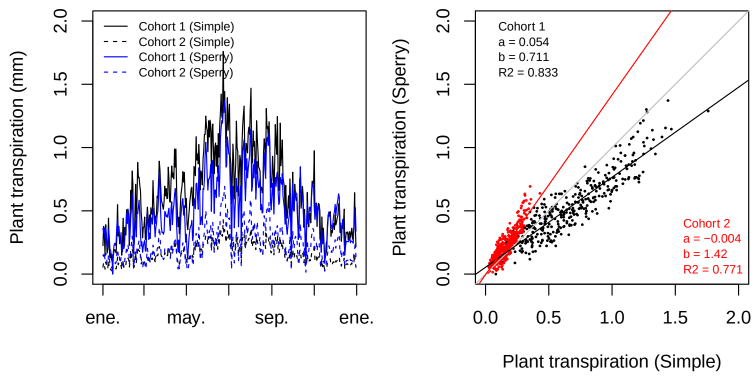


If we examine the water fluxes from each soil layer we find a strong correlation between regulation modes, but Sperry's model consistently draws more water from layer 2 because root conductance is higher for this layer, despite the fact that fine root distribution is the same as with Simple regulation model.



2.2 Two cohorts

We ran the same day-to-day simulations on `forest2` (code not shown). The agreement regarding the transpiration predicted for each plant cohort is a bit lower but still very high. The deviation from the one-one line should be interpreted as the result of differences in how light extinction is translated into leaf energy balance and, hence, transpiration in the two regulation models.



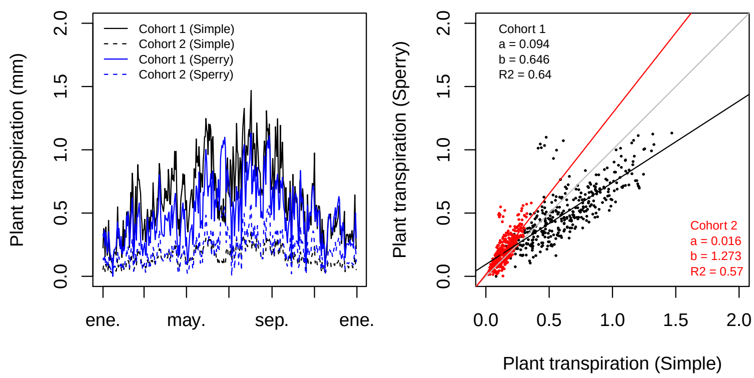
3 Simulations with soil moisture dynamics

3.1 Independent soil moisture dynamics

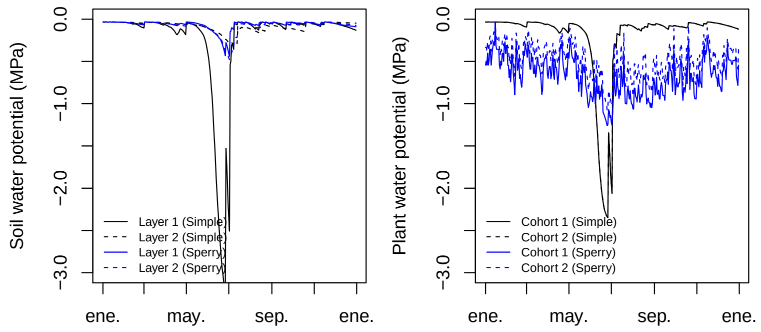
In a dynamic context the choice of a regulation mode will affect soil moisture dynamics. In turn, different soil moisture dynamics can affect the transpiration predicted by the two regulation modes. To examine the effect of these feedbacks, we carried out simulations using `forest2` (i.e. two cohorts) and the usual `swb` function:

```
> examplesoil1 = soil(sp)
> examplesoil2 = soil(sp)
> control$transpirationMode="Simple"
> x1 = forest2swbInput(forest2,examplesoil1, SpParamsMED, control)
> control$transpirationMode="Complex"
> x2 = forest2swbInput(forest2,examplesoil2, SpParamsMED, control)
> S1 = swb(x1, examplesoil1, examplemeteo[days,])
> S2 = swb(x2, examplesoil2, examplemeteo[days,], latitude, elevation,0,0)
```

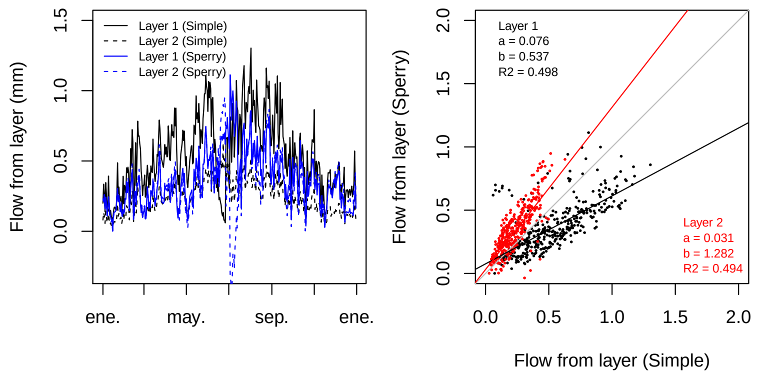
When we inspect the amount of water transpired, we find almost no differences, except for a short period in summer where soil moisture is limiting transpiration in the Simple regulation mode. These days can be identified in the scatter plots as outliers above the regression lines:



If we inspect soil and plant water potentials, we find very different dynamics. The reason is that the Sperry model allows hydraulic redistribution, so that the two soil layers are constantly re-equilibrated in terms of moisture and water potential, whereas under the Simple regulation mode one layer (in this case the topsoil) may get much drier easily. Since in the Simple regulation mode plant water potentials are a non-linear average of soil potentials, the same drop is seen in the plant water potentials (both cohorts have the same potential because they share the same transpiration parameter value). In the Sperry regulation mode (mid-day) water potentials vary slightly during the year, although they get more negative in summer.



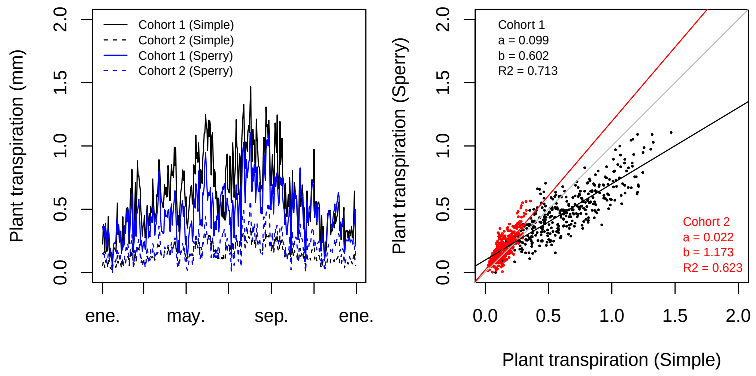
Inspection of flow values from soil layers allows identifiying the periods where the Sperry model causes more redistribution, besides the already known effect of drawing more water form the subsoil than in the Simple model.



3.2 Forced soil moisture dynamics

We finally repeated simulations with Sperry regulation mode, but forcing soil moisture dynamics to be those predicted by the Simple regulation mode. This should allow us to see the agreement between the transpiration of the two models under the same moisture dynamics.

The results show that the agreement in transpiration is similar to that of the previous simulations.



Even if soil moisture levels are the same, with Sperry regulation mode the amount of water transpired during drought can be higher because in this case the model takes more water from the moister layer (topsoil) and puts it into the drier layer (subsoil), bringing the plant water potential to a less negative value than the soil average calculated using the Simple regulation mode. This hydraulic redistribution is exagerated here because of forcing soil moisture dynamics from the Simple regulation mode.