VOM

Jul 15, 2022

Contents:

The vegetation optimality model was developed to model the water use by natural vegetation for use in hydrological models. The aim of the model is to predict vegetation water use based on meterological information, soils and topography only, without the need for prescribing site-specific vegetation properties or calibration against observed fluxes.

CHAPTER 1

Quickstart

1.1 Dependencies

Before starting, make sure an appropriate fortran compiler is installed. The code has been tested and developed mainly with gfortran.

In addition, make sure the netcdf-fortran library is installed:

```
sudo apt install netcdf-bin libnetcdf-dev libnetcdff-dev
```

The VOM will by default search for the netcdf installation in usr/include.

1.2 Compiling and testing the model

To compile the model on a unix machine with the gfortran compiler, type :

```
make
```

This will create an executable file called "model.x". Now test the model by typing:

```
make check
```

When the test is passed, the model is ready to use. The VOM_namelist contains all settings, and the model should always be run with the directory of this namelist as working directory. Input and output directories can be defined in the namelist with absolute or relative paths from the working directory.

1.3 Running the model

The executable "model.x" can be run :

```
./model.x
```

To run successfully, these input-files are needed:

vom_namelist Contains all settings to run the VOM.

pars.txt Contains the (optimized) vegetation parameters (only needed for single run).

dailyweather.prn Contains the meteorological forcing.

By default, the executable looks for the vom_namelist in the current workdirectory. The default directory for the other files is /input, relative to the workdirectory. This can be changed in vom_namelist, or on the command line:

-i Inputpath to directory with dailyweather.prn, and optionally pars.txt.

-o Outputpath for all outputfiles.

-n The VOM_namelist (filename can be different)

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-i Inputpath to directory with dailyweather.prn, and optionally pars.txt.

-o Outputpath for all outputfiles.

-n The VOM_namelist (filename can be different)

1.4 Scripts for running the model

In the folder VOM-scripts, two shell-scripts can be found for running the VOM:

```
vom_parallel.job


run_vom.sh
```

The model is compiled and executed by the script run_vom.sh. It can be used in the following way:

```
bash src_sh/run_vom.sh src/VOM/VOM_Fortran/ <inputdir> <dailyweather.prn>
↪<soilprofile.par> <vom_namelist> <outputdir>
```

vom_parallel.job is a job script for the LIST HPC using SLURM. Note that the script needs to be modified for own applications of the VOM on an HPC and serves here as an example. In this example, submitting a job with SLURM functions as follows:

```
sbatch -o <output_logfile> -e <error_logfile> -n <number of cpu's> -J <jobname> vom_
↪parallel.job <VOM-src> <input-directory> <dailyweather.prn> <soilprofile.par> <vom_
↪namelist> <output-directory>
```

1.5 Model modes

The model can be run in 4 different modes, defined by VOM_command in the VOM_namelist:

1 Optimize the model with the Shuffled Complex Evolution algorithm.

2 Run without optimization, based on the parameters in pars.txt.

3 Run without optimization, based on the parameters in pars.txt. Returns only NCP values as output.

4 Run the model with a set of random parameters.

1.6 Other options

Initially, the VOM schematized the vegetation as two big leaves, for the perennial and seasonal vegetation. In the newest VOM version, leaf area dynamics can be included in a dynamic way as well, by setting the parameter i_lai_function in the VOM_namelist:

1 No LAI dynamics are included.

2 LAI is dynamically modelled, but there is no distinction between shaded and sunlit leaves, as well as different radiation components.

3 LAI is dynamically modelled. Shaded and sunlit fractions are determined and a distinction between direct and diffuse radiation is made, but leaves are still treated as a big leave with a single photosynthetic capacity.

4 LAI is dynamically modelled. Shaded and sunlit fractions are determined and a distinction between direct and diffuse radiation is made. The model considers shaded and sunlit leaves with different photosynthetic capacities. Eletron transport capacities are separately optimized for shaded and sunlit leaves.

CHAPTER 2

VOM_namelist

The file "vom_namelist" is an input file for the VOM, containing all settings for the model runs:

i_alpha	initial slope of j(par) curve	-
i_cpccf	water transport cost factor (cpcc=pc * rootdepth * cpccf)	mol/m^3/s
i_tcfg	turnover cost factor for foliage grasses (tc=tcf*LAI)	mol/m^2/s
i_tcft	turnover cost factor for foliage trees (tc=tcf*LAI)	mol/m^2/s
i_maxyear	number of years to process	-
i_testyear	number of years after which to perform initial test of netass	-
i_ha	parameters to calculate jmax(temp)	J/mol
i_hd	parameters to calculate jmax(temp)	J/mol
i_toptf	parameter to calculate adaptation of topt (range 0-1, 0.0 means no adaptation, 1.0 means topt=tair)	-
i_toptstart	start parameter for topt to calculate jmax	K
i_rlratio	leaf respiration parameter (rl=rlratio*assmax)	-
i_mdtf	total dry mass of living tissues of trees per unit pc	g/m^2
i_mqxtf	total water storage capacity in living tissues of trees per unit md	•
i_rrootm	root water uptake resistivity	s
i_rsurfmin	minimum root area to be maintained	m^2/m^3
i_rsurf	initial root surface area	m^2/m^3
i_rootrad	fine root radius	m

Continued on next page

Table 1 – continued from previous page

i_prootmg	constant root balance pressure in grasses	m
i_growthmax	parameter determining maximum daily growth increment of root surface area	m^2/m^3/d
i_incrcovg	parameter determining maximum increment percentage of grass cover	-
i_incrjmax	parameter determining maximum increment percentage of jmax25	-
i_jmax_ini	parameter determining the start value of jmax25	mol/m^2/s
i_incrlait	parameter determining maximum increment percentage of LAI grasses	-
i_incrlaig	parameter determining maximum increment percentage of LAI trees	-
i_firstyear	firstyear for the generation of hourly output in computation mode	-
i_lastyear	lastyear for the generation of hourly output in computation mode	-
i_write_h	flag to greate a file with hourly values from daily values	-
i_read_pc	flag to read vegetation coverage values from file	-
i_write_nc	flag to write to netcdf instead of plain text	-
i_trans_vegcov	fraction of radiative energy reaching soil under full cover (0-1)	-
i_lai_function	switch for 1) no LAI dynamics, 2) dynamic LAI, 3) dynamic LAI with shaded/sunlit fractions, 4) dynamic LAI with shaded/sunlit fractions and different Jmax for shaded/sunlit fractions	- -
i_no_veg	switch for running VOM without vegetation (0-with, 1-without)	-
i_chi_g	ratio projected areas of grass canopy elements on horizontal and vertical surfaces (-)	-
i_chi_t	ratio projected areas of tree canopy elements on horizontal and vertical surfaces (-)	-
i_inputpath	path to folder with inputfiles	-
i_outputpath	path to folder with outputfiles	-
o_lambdagf	factor for calculating lambdag_d	mol/mol/m
o_wsgexp	exponent for calculating lambdag	-
o_lambdatf	factor for calculating lambdat_d	mol/mol/m
o_wstexp	exponent for calculating lambdat_d	-
o_cait	projected cover perennial vegetation (0-1)	-
o_rtdepth	tree rooting depth	m

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Table 1 – continued from previous page

o_mdstore	wood water storage parameter of trees (can be in shufflepar)	g/m^2
o_rgdepth	root depth grasses (can be in shufflepar)	m
i_lat	geogr. latitude in degrees	degrees
i_lon	geogr. longitude in degrees	degrees
i_cz	average soil elevation	m
i_cgs	Capital Gamma S (length scale for seepage outflow REG)	m
i_zr	average channel bed elevation	m
i_go	slope close to channel	rad
i_ksat	Saturated hydraulic conductivity	m/s
i_thetar	residual soil moisture	-
i_thetas	saturated soil moisture	-
i_nvg	van Genuchten soil parameter n	-
i_avg	van Genuchten soil parameter alpha	1/m
i_delz	thickness of soil sublayers	m
vom_command	COMMAND LINE TO RUN ASSIMILATION MODEL	-
i_ncomp	MAXIMUM NUMBER OF COMPLEXES (p)	-
i_ncompmin	MINIMUM NUMBER OF COMPLEXES (pmin)	-
i_resolution	RESOLUTION OF OPTIMISATION (% OF MAX VARIATION WHEN OPTIMISATION STOPS)	-
i_patience	NUMBER OF LOOPS WITHOUT INCREASE IN OF BEFORE OPTIMISATION STOPS	-
i_nsimp	NUMBER OF OPTIMISATIONS PER COMPLEX AND RUN	-
i_focus	IF <1.0, THE SPREAD OF THE RANDOM SEED AROUND THE INITIAL VALUES IS LIMITED	-
i_iter	Maximum iterations in case of random runs	-
vom_npar	number of parameters in shuffle2par used for optimization in SCE	-
n_thread	number of threads to be used in parallel	-
sce_restart	restart SCE from previous run	-
runtime_limit	time in minutes before sce stops	minutes
parname0	list of parameter names	-
parval0	list of default parameter values	-
parmin0	list of minimum parameter values	-
parmax0	list of maximum parameter values	-
paropt0	list of parameters to optimize (0-1)	-

CHAPTER 3

Meteorological forcing

The file "dailyweather.prn" is an input file for the VOM, containing all meteorologicald data:

Dcum	Day of the year	Integer
Day	Day of the month	Integer
Month	Month of the year	Integer
Year	Year	Integer, 4 digits
T.Max	Daily max. Air temp in °C	Decimal, #.##
T.Min	Daily min. Air temp in °C	Decimal, #.##
Rain	Daily rain fall in mm	Decimal, #.##
Radn	Global solar irradiance in MJ/m2	Decimal, #.##
VP	Water vapour pressure in hPa	Decimal, #.##
Pres	air pressure in hPa	Decimal, #.##
Ca	ambient air CO2 concentration in µmol	Decimal, #.##

The first line contains the variable names and is omitted when reading the file. All fields are 8 characters long and need to be filled from behind, e.g.:

NOTE: when creating your own dailyweather.prn, make sure the alignments are exactly the same as the example input I.e. in the following format: %8.0f%8.0f%8.0f%8.0f%8.2f%8.2f%8.2f%8.2f%8.2f%8.2f%8.2f

CHAPTER 4

Soil data

4.1 Soil layers

Soil layer thickness is globally defined with the parameter i_delz, or in the file soilprofile.par for each soil layer separately. The sum of the soil layers need to be equal to the topographical parameter i_cz (maximum elevation). The VOM will raise a warning and correct i_cz if this is not the case. The river bed level i_zr needs to align with the soil layers. Also here, the VOM will give a warning and correct i_zr if needed.

4.2 Soil properties

Soil water retention and hydraulic conductivity parameters for 12 major soil textural groups according to[1]. Some units of the parameters (alpha and Ksat) are converted for the use in the VOM.

Texture	theta-r	theta-s	alpha (1/m)	n	K-sat (m/s)
Sand	0.045	0.43	14.5	2.68	8.25*10-5
Loamy Sand	0.057	0.41	12.4	2.28	4.053*10-5
Sandy Loam	0.065	0.41	7.5	1.89	1.228*10-5
Loam	0.078	0.43	3.6	1.56	2.889*10-6
Silt	0.034	0.46	1.6	1.37	6.944*10-7
Silt Loam	0.067	0.45	2.0	1.41	1.25*10-6
Sandy Clay Loam	0.100	0.39	5.9	1.48	3.639*10-6
Clay Loam	0.095	0.41	1.9	1.31	7.222*10-7
Silty Clay Loam	0.089	0.43	1.0	1.23	1.944*10-7
Sandy Clay	0.100	0.38	2.7	1.23	3.333*10-7
Silty Clay	0.070	0.36	0.5	1.09	5.555*10-8
Clay	0.068	0.38	0.8	1.09	5.555*10-7

[1] Carsel, R.F. & R.S.Parrish (1988): Developing joint probability distributions of soil water retention characteristics.-Water Resource Research 24:755-769.

CHAPTER 5

Outputfiles

Output files can by default created in plain text format, but can also be set to netcdf by changing the flag i_write_nc to .True.

5.1 results_daily.txt

The file "results_daily.txt" is an output file from VOM, containing daily weather, flux and state variable data in ascii format, e.g.:

fyear	Day of the year
fmonth	Month of the year
fday	Day of the month
nday	Day of the model
nhour	Last hour of day
rain	Daily rain fall in mm/d
tairmax	Daily max. Air temp in °C
tairmin	Daily min. Air temp in °C
par	Photosynthetically active Photon Flux Density (in mol m-2 d-1)
vd	Daily average atmospheric vapour deficit (in mol mol-1)
esoil	Daily soil evaporation rate (m d-1)
jmax25t	Electron transport capacity at 25oC by trees (in mol m-2 s-1)
jmax25g	Electron transport capacity at 25oC by grasses (in mol m-2 s-1)
jmax25ts	Electron transport capacity at 25oC by trees, shaded part (in mol m-2 s-1)
jmax25gs	Electron transport capacity at 25oC by grasses, shaded part (in mol m-2 s-1)
pc	Area fraction covered by grasses and trees combined
rlt	Daily leaf respiration rate by trees (in mol m-2 d-1)
rlh	Daily leaf respiration rate by grasses (in mol m-2 d-1)
lambdat	dE/dA in trees, in mol/mol
lambdag	dE/dA in grasses, in mol/mol
rrt	Daily root respiration rate by trees (in mol m-2 d-1)

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Table 1 – continued from previous page

rrg	Daily root respiration rate by grasses (in mol m-2 d-1)
asst	CO2 uptake rate by trees (in mol m-2 d-1)
assg	CO2 uptake rate by grasses (in mol m-2 d-1)
su_avg	Average soil saturation degree in the unsaturated zone at midnight (dimensionless)
zw	Thickness of the saturated zone (in m)
ws	Total soil water storage (in m)
spgfcf	Daily seepage face flow (=subsurface runoff, in m d-1)
infx	Daily infiltration excess runoff (in m d-1)
etmt	Daily transpiration rate by trees (in m d-1)
etmg	Daily transpiration rate by grasses (in m d-1)
su_1	Soil saturation degree in the top soil layer at midnight (dimensionless)
topt	Optimal temperature for photosynthesis (in oC)
tcg	Grass foliage turnover costs (mol/m2/s)
tct	Tree foliage turnover costs (mol/m2/s)
cpccg_d	Grass water transport costs (mol/m2/s)
cpcct_d	Tree water transport costs (mol/m2/s)
fsun_t	Fraction of sun trees (-)
fshade_t	Fraction of shade trees (-)
fsun_g	Fraction of sun grasses (-)
fshade_g	Fraction of shade grasses (-)
lai_t	Leaf area index trees (-)
lai_g	Leaf area index grasses (-)
lai_tot	Total leaf area index (-)
cai_g	Crown area index grasses (-)
ncp_g	Daily Net Carbon profit grasses (in mol m-2)
ncp_g	Daily Net Carbon profit trees (in mol m-2)

5.2 results_hourly.txt

fyear	Day of the year
fmonth	Month of the year
fday	Day of the month
nday	Day of the model
nhour	Hour
rain	Rainfall rate in m/s
tair	Air temp in °C
par	Photosynthetically active Photon Flux Density (in mol m-2 s-1)
vd	Atmospheric vapour deficit (in mol mol-1)
esoil	Hourly soil evaporation rate (m h-1)
jmax25t	Electron transport capacity at 25oC by trees (in mol m-2 s-1)
jmax25g	Electron transport capacity at 25oC by grasses (in mol m-2 s-1)
pc	Area fraction covered by grasses and trees combined
mqt	Tissue water content in trees (in kg m-2)
rl	Leaf respiration rate by trees and grasses combined (in mol m-2 s-1)
lambdat	dE/dA in trees, in mol/mol
lambdag	dE/dA in grasses, in mol/mol
rr	Rroot respiration rate by trees and grasses combined (in mol m-2 s-1)
asst	Hourly CO2 uptake rate by trees (in mol m-2 h-1)
assg	Hourly CO2 uptake rate by grasses (in mol m-2 h-1)
zw	Thickness of the saturated zone (in m)
ws	Total soil water storage (in m)
spgfcf	Hourly seepage face flow (=subsurface runoff, in m h-1)
infx	Hourly infiltration excess runoff (in m h-1)
etmt	Hourly transpiration rate by trees (in m h-1)
etmg	Hourly transpiration rate by grasses (in m h-1)
su_1	Soil saturation degree in the top soil layer at midnight (dimensionless)

5.3 results_yearly.txt

nyear	Year
rain	Annual rainfall (mm/year)
par	Photosynthetically active Photon Flux Density (in mol m-2 s-1)
srad	Global solar irradiance (in MJ m-2 a-1)
vd	Yearly average vapour deficit (in mol mol-1)
esoil	Yearly soil evaporation rate (mm/year)
etmt	Yearly transpiration rate by trees (in mm/year)
etmg	Yearly transpiration rate by grasses (in mm/year)
assg	CO2 uptake rate by seasonal vegetation (in mol m-2 a-1)
asst	CO2 uptake rate by trees (in mol m-2 a-1)
rlg	Leaf respiration rate by seasonal vegetation (in mol m-2 a-1)
rrg	Root respiration rate by seasonal vegetation (in mol m-2 a-1)
rlt	Leaf respiration rate by perennial vegetation (in mol m-2 a-1)
rrt	Root respiration rate by perennial vegetation (in mol m-2 a-1)
cpccg	Carbon costs related to water distribution and storage for seasonal vegetation (in mol m-2 a-1)
tcg	Carbon costs related to maintenance of gras foliage (in mol m-2 a-1)
cpcct	Carbon costs related to water distribution and storage for perennial vegetation (in mol m-2 a-1)
tct	Carbon costs related to maintenance of tree foliage (in mol m-2 a-1)

5.4 rsurf_daily.txt

The file “rsurf_daily.txt” is an output file from VOM, containing a midnight snapshots of the root surface distributions in the soil profile in ascii format.

As the number of soil layers also depends on given soil depth, this file has a variable number of columns. These columns do not have their own variable names. They are all saved within and behind the last variable name (rsurft_sublayer), e.g.:

fyear	Year
fmonth	Month of the year
fday	Day of the month
nday	Day of the model
rsurft_sublayer	Root surface area density (root surface area per unit soil volume) in each soil layer (in m2 m-3 d-1)

5.5 ruptk_hourly.txt

The file “ruptkt_hourly.txt” is an output file from VOM, containing hourly root water uptake rates in each soil layer during the last few years of the model run in ascii format.

As the number of soil layers also depends on input given soil depth, this file has a variably number of rows. These rows don’t have their own variable names. They are all saved within and behind the last variable name (delyusublayer), e.g.:

fyear	Year
fmonth	Month of the year
fday	Day of the month
nday	Day of the model
ruptkt_sublayer	Root water uptake rate in each soil layer (in m h-1)

5.6 su_hourly.txt

The file "su_hourly.txt" is an output file from VOM, containing hourly soil saturation degrees in each soil layer during the last few years of the model run in ascii format.

As the number of soil layers also depends on input given soil depth, this file has a variably number of rows. These rows don't have their own variable names. They are all saved within and behind the last variable name (su_sublayer), e.g.:

fyear	Year
fmonth	Month of the year
fday	Day of the month
nday	Day of the model
su_sublayer	Soil saturation degree in each sublayer (1.0 means fully saturated)

5.7 delz_hourly.txt

The file "delz_hourly.txt" is an output file from VOM, containing the thickness of each unsaturated soil layers in ascii format.

As the number of soil layers also depends on the position of the water table, this file has a variable number of rows. These rows do not have their own variable names. They are all saved within and behind the last variable name (delz_sublayer), e.g.:

fyear	Year
fmonth	Month of the year
fday	Day of the month
nday	Day of the model
delz_sublayer	Thickness of each unsaturated soil layer (in m)

CHAPTER 6

Shuffled Complex Evolutionary algorithm

The Shuffled Complex Evolutionary algorithm of Duan et al. (1994) is used to optimize the VOM. The main settings can be found in the VOM_namelist:

i_ncomp	MAXIMUM NUMBER OF COMPLEXES (p)	-
i_ncompmin	MINIMUM NUMBER OF COMPLEXES (pmin)	-
i_resolution	RESOLUTION OF OPTIMISATION (% OF MAX VARIATION WHEN OPTIMISATION STOPS)	-
i_patience	NUMBER OF LOOPS WITHOUT INCREASE IN OF BEFORE OPTIMISATION STOPS	-
i_nsimp	NUMBER OF OPTIMISATIONS PER COMPLEX AND RUN	-
i_focus	IF <1.0, THE SPREAD OF THE RANDOM SEED AROUND THE INITIAL VALUES IS LIMITED	-
i_iter	Maximum iterations in case of random runs	-
vom_npar	number of parameters in shuffle2par used for optimization in SCE	-
n_thread	number of threads to be used in parallel (one complex per thread)	-
sce_restart	restart SCE from previous run, TRUE or FALSE	-
runtime_limit	time in minutes before sce stops at it's earliest possibility	minutes

The SCE-algorithm (mode 1) can be run in parallel by setting the number of threads. When specified, the SCE-algorithm runs over the different complexes in parallel (one complex per thread). The maximum runtime (in minutes) can be set, after which the algorithm tries to stop at the earliest possibility. Afterwards, the SCE-algorithm can be restarted when sce_restart is set to TRUE and the files of the previous round are available.

6.1 Outputs

After the SCE-algoritm finishes, it runs the VOM once more with the optimized parameters. It creates the same files as for a single run, as can be found in the section on the outputs for a single run (see outputfiles).

File-name	Description
sce_progress.txt	Gets progressively filled with messages as the model runs.
sce_out.txt	Gets progressively filled with an experimental parameter set and the respective value of the objective function. Contains a line for every parameter set explored, composed of the parameter values followed by the value of the objective function.
sce_lastloop.txt	Written at the end of each optimisation loop and contains all information needed to continue with the next loop, i.e. the number of complexes the number of previous loops, the number of runs performed already, the number of runs since the best objective function was achieved, followed by all the parameter sets explored in the last completed loop and their respective objective function values (similar as sce_out.txt, but limited to the last loop only).
sce_lastbest.txt	Contains the best parameter set and objective function of the most recent loop.
sce_bestpars.txt	Written whenever a parameter set is found that yields the best objective function value.
sce_status.txt	Created when optimisation finished successfully, contains one ascii symbol: “1”

CHAPTER 7

Background

7.1 Equations

equations.pdf Pdf-file with equations for vegetation transport model.

Watbal3.pdf Pdf-file with equations regaring the water balance.

7.2 Literature

Schymanski, S.J., Sivapalan, M., Roderick, M.L., Hutley, L.B., Beringer, J., 2009. An optimality-based model of the dynamic feedbacks between natural vegetation and the water balance. Water Resources Research 45. https://doi.org/10.1029/2008WR006841

7.3 Source code

https://github.com/schymans/VOM/

CHAPTER 8

Indices and tables

- genindex
- modindex
- search

CHAPTER 9

Theory

The original theory and equations used in the model are described in:

S. J. Schymanski. Transpiration as the Leak in the Carbon Factory: A Model of Self-Optimising Vegetation. PhD thesis, University of Western Australia, Perth, Australia, 2007.

CHAPTER 10

Information

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Code availability: https://github.com/schymans/VOM

Date of first version: April 2006