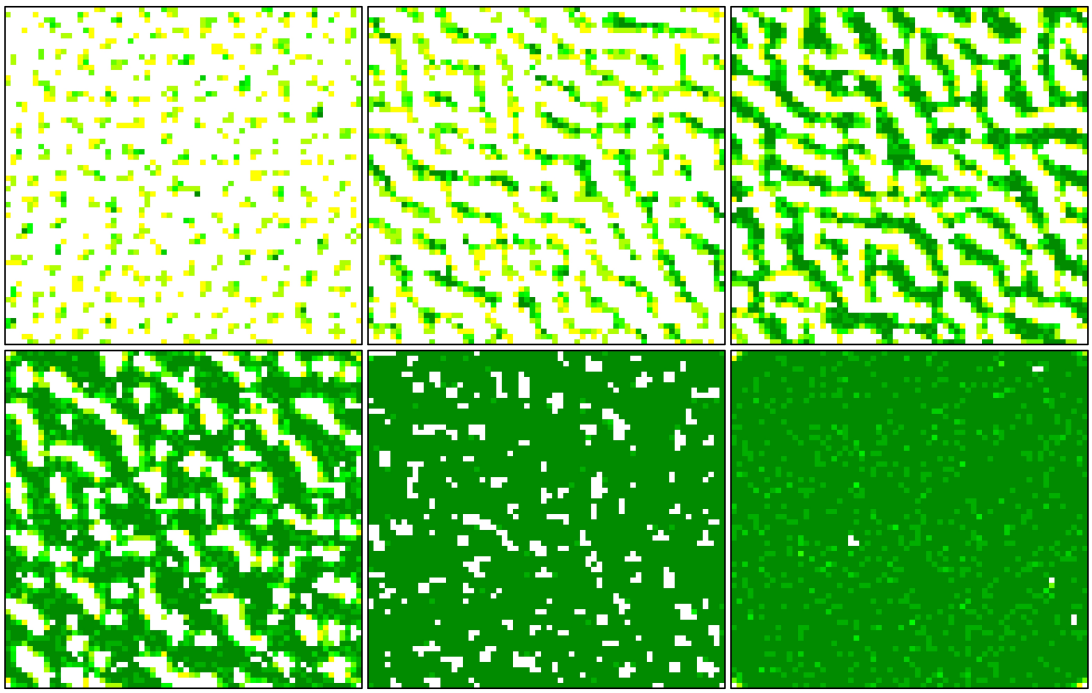
Ecohydraulical Feedback Simulation Documentation and Manual



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Draft status

- Suggestions for overall structuring welcomed!
- what means Dimensions: [:,:] ?
- subroutines and comments on the variables are from file `coupledModel.f90`
- `\subroutine{<name>}{<arguments>}` for displaying a subroutine with its arguments. <name> automatically gets an (emphasized) index entry and a label.
- `\inout{<input entries>}{<output entries>}` is for a list of input and output arguments. Missing values get replaced by "no input" or "no output".
- `\inoutentry[<option>]{<variableName>}{type}{dimensions}{description}` for an entry in the input output list. <option> can be empty or "emph" for an emphasized index entry or "none" for no index entry.
- `\begin{usessubs}` is an environment of used subroutines.
- `\usessubentry{<subroutineName>}` is for an entry in the `usessubs` environment. Entries automatically get an (not emphasized) index entry and a reference to the associated subroutine.
- I am using the keyword index to index all parameter and variable names. Good idea? Or shall we make a list with all parameter and variable names and their description and unit? Like:

Table 1: variables

variable	type	dimensions	nom	unit	description
`climParams`	[8-byte real]	[4]			climate parameters
`infiltParams`	[8-byte real]	[6]			vegetation and soil kernel parameters
`evapParams`	[8-byte real]	[8]			evaporation parameters
`discharge`	[integer]	[m,n]	Q	$[\mathrm{m}^3/\mathrm{s}]$	discharge
`alpha`	[8-byte real]	[m,n]	α		

My suggestion for collaboration: let's use the package "trackchanges". Nanu: Editing [could look like this] with the following commands:

```
\add[editor]{added text}

\remove[editor]{removed text}

\change[editor]{removed text}{added text}

\note[editor]{note text}

\annote[editor]{text to annotate}{note text}
```

1 Introduction

2 Theoretical principles

2.1 Simulation model

Runoff, soil moisture storage, transpiration and plant-bare soil transitions are numerically modeled on a lattice of square cells. The model simulates the following spatially distributed water balance:

$$\frac{\partial w_i}{\partial t} = P_i + R_i - Q_i - E_i - \sum_n T_n \tag{1}$$

2.2 Runoff generation

2.3 Surface water flow

2.4 Short range facilitation

2.5 Evaporation and transpiration

2.6 Vegetation change

2.7 Microtopography

System Variables	Symbol	Value	Variable Name
Mean annual rainfall (m)	D	0.2	pa
Mean annual dry duration (yr)	t_e	0.1	
Grid size (m)	Δx	0.1	dx
Intrinsic hydraulic conductivity (-)	$\widetilde{K}_0$	0.1	K0
Maximum potential hydraulic conductivity (-)	$\widetilde{K}_max$	0.9	Kmax

Table 2: Example Parameter Values Used by Mcgrath et al. (2012)

3 Application

3.1 Build from source

3.1.1 Unix Systems

To use the gfortran compiler execute the following in terminal:

```
gfortran coupledModel.f90
```

On Unix systems an `.out` file is generated. To execute this, type the following into the terminal:

```
./a.out
```

3.2 Installation

3.2.1 System requirements

3.3 Application prerequisites

3.4 Data preperation

3.5 Parameterization

3.5.1 Example Parameters

3.6 Simulation

3.7 Output

3.8 Appraise and visualize results

3.8.1 in R

3.8.2 in R and LaTeX (knitr-method)

```
http://yihui.name/knitr/
```

3.8.3 in Excel

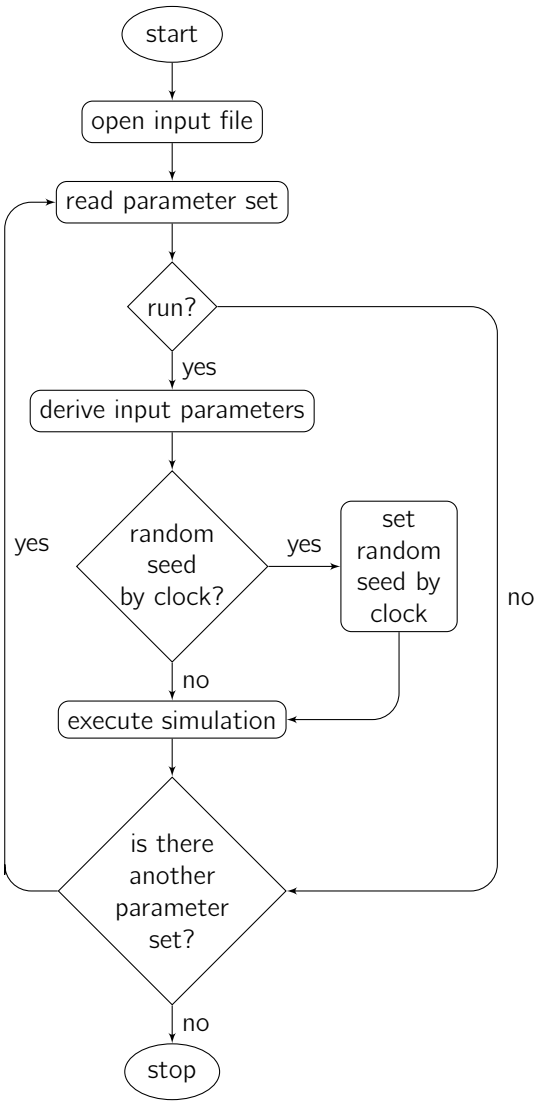

Figure 1: flow chart of the main program

4 Implementation

4.1 Overview

4.2 Implementation strategy

4.3 Subroutines

4.3.1 Simulation

```
SimCODE(m, n, mn, simflags, climParams, infiltParams, evapParams,
vegParams, erParams, resultsFID)
```

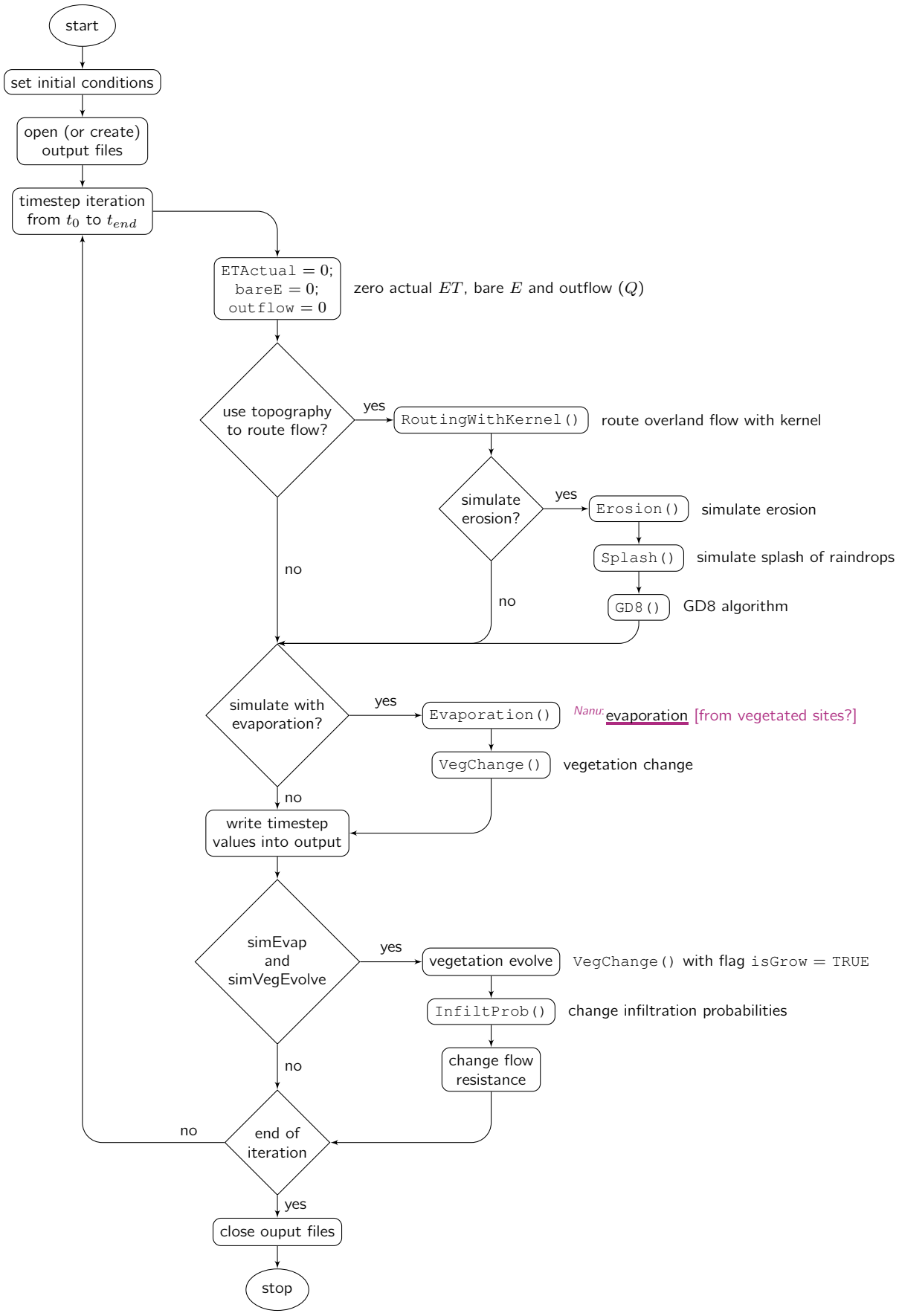

Figure 2: flow chart of subroutine `SimCode` (simulation execution)

input

`m`	[integer]		number of rows
`n`	[integer]		number of colums
`mn`	[integer]		= m·n
`simflags`	[integer]	[6]	[1] ... is for this, [2] ... is for that, Nanu: [should be explained!]
`climParams`	[8-byte real]	[4]	Nanu: climate parameters [how to input these?]
`infiltParams`	[8-byte real]	[6]	Nanu: ~~vegetation and~~ soil kernel parameters
`evapParams`	[8-byte real]	[8]	evaporation parameters
`vegParams`	[8-byte real]	[5]	vegetation Nanu: ~~and soil kernel~~ parameters
`erParams`	[8-byte real]	[4]	Nanu: vegetation and soil kernel parameters [what specific?]
`resultsFID`	[character]	[len=8]	results file id code

output

no output

Uses subroutines:

`GD8()`, cf. page 13
`InfiltProb()`, cf. page 9
`RoutingWithKernel()`, cf. page 9
`Erosion()`, cf. page 10
`Splash()`, cf. page 10
`Evaporation()`, cf. page 11
`VegChange()`, cf. page 15

4.3.2 Green-ampt infiltration

`GAInfilt``(m, n, dt, inflow, Ksat, wfs, cumInfilt, infex)`

Nanu: Green-ampt infiltration calculation. [Literature?]

input

`m,n`	[integer]		
`dt`	[8-byte real]		
`inflow`	[8-byte real]	[m,n]	surface runon + precipitation $(R + P)$
`wfs`	[8-byte real]	[m,n]	Nanu: wetting front suction * moisture deficit [formula?]
`cumInfilt`	[8-byte real]	[m,n]	Nanu: cumulative infiltration [nomenclature?]

output

`infex`	[8-byte real]	[m,n]	infiltration excess
`cumInfilt`	[8-byte real]	[m,n]	cumulative infiltration

4.3.3 Nanu: TwoDRandPos [cannot guess what this means]

`TwoDRandPos``(randOrder, m, n, mn)`

input

`m,n`	[integer]	
`randOrder`	[integer]	[mn,2]

output

`randOrder`	[integer]	[mn,2]

Uses subroutines:
`OneDRandList()`, cf. page 8

4.3.4 Kinematic wave primer

`KWPrimer``(m, n, topog, manningsN, mask, solOrder, flowdirns, alpha, deltax, solMax)`

Iterate over space to generate calculation a mask. The mask is a 9 x 1 array where 1s indicate that a neighbour (as defined by the position in mask(x,y)) discharges to the cell at x,y

input

`m,n`	[integer]		
`topog`	[integer]	[`mn,n`]	
`manningsN`	[integer]	[`mn,n`]	

output

`deltax`	[8-byte real]	[`m,n`]	
`alpha`	[8-byte real]	[`m,n`]	
`solMax`	[integer]		
`solOrder`	[integer]	[`m,n`]	
`flowdirns`	[integer]	[`m,n`]	flow directions
`mask`	[integer]	[`m,n,9`]	

Uses subroutines:
`GD8()`, cf. page 13
`KMWOrder()`, cf. page 8
`Neighbours()`, cf. page 12
`Lookupfdir()`, cf. page 8

4.3.5 Kinematic wave

`KinematicWave``(m, n, ndx, dt, iex, flowdirns, solOrder, solMax, mask, alpha, deltax, disOld, disNew)`

This subroutine calculates the kinematic wave equation for surface runoff in a network for a single time step. The flow network is given by the GD8 algorithm calculated on the topography. We assume no interaction between adjacent flow pathways i.e. water does not overflow in a direction not specified by the GD8 network. `iex` is the excess water from Nanu: precip - infiltration + GW discharge [display as formula?].

$$iex(m, n, 1) = qit$$

Nanu: [should this be displayed as formula or as code?]

$$iex(m, n, 2) = qitPlus$$

Nanu: `manningsN` the roughness coefficient [is this in the right place?]

Nanu: `init` a value passed to initialise the variables [same for this]

input

m,n	[integer]		
ndx	[integer]		
solMax	[integer]		
flowdirns	[integer]	[m,n]	flow directions
solOrder	[integer]	[m,n]	
mask	[integer]	[m,n]	
alpha	[8-byte real]	[m,n]	
deltax	[8-byte real]	[m,n]	
dt	[8-byte real]		time step
disOld,disNew	[8-byte real]	[m,n,ndx]	
iex	[8-byte real]	[m,n,2]	

output

disOld, disNew	[8-byte real]	[m,n,ndx]

4.3.6 Kinematic wave order

KMWOrder(flowdirns, m, n, solutionOrder)

Subroutine assigns values to the matrix solutionOrder to tell the Kinematic Wave subroutine in which order to solve the KM equation on the drainage network. Values of 1 assigned to top of catchment, 2 to 1st downstream node etc.. Value at a point is the maximum travel distance to that point from all points above it.

input

m,n	[integer]		
flowdirns	[integer]	[m,n]	flow directions

output

solutionOrder	[integer]	[n,n]

Uses subroutines:
Lookupfdir(), cf. page 8

4.3.7 OneDRandList(a,mn)

OneDRandList(a, mn)

input

mn	[integer]	
a	[integer]	[mn,2]

output

a	[integer]	[mn,2]

4.3.8 Lookup for direction

Lookupfdir(dirn, dx, dy)

input

dirn	[integer]

output

dx,dy	[integer]

4.3.9 Routing with kernel

RoutingWithKernel(m, n, mn, precip, infiltKern, storeKern, newflowdirns, topog, store, discharge, outflow)

This subroutine routes water particles through the landscape.

input

m,n	[integer]		
mn	[integer]		
infiltKern	[8-byte real]	[m,n]	infiltration probability
storeKern	[8-byte real]	[m,n]	storage capacity
topog	[8-byte real]	[m,n]	topography
precip	[integer]	[m,n]	rainfall
store	[integer]	[m,n]	
newflowdirns	[integer]	[m,n]	flow directions

output

outflow	[integer]		cumulative outflow (leaving model domain)
store	[integer]	[m,n]	water infiltrated
newflowdirns	[integer]	[m,n]	new flow directions
discharge	[integer]	[m,n]	cumulative amount of overland flow

Notice: Periodic boundary conditions can only really be defined simply for an inclined plane with two adjacent edges defined as the boundary from which particles are routed to the opposite boundary. For simplicity it is assumed that the landscape slopes downwards in the direction of lower x and y.

Uses subroutines:

OneDRandList(), cf. page 8
TwoDRandPos(), cf. page 6
Lookupfdir(), cf. page 8
Neighbours(), cf. page 12
fdirLookup(), cf. page 14

4.3.10 Infiltration Probability

InfiltProb(veg, m, n, K0, ie, rfx, rfy, kf, Kmax, dx, dy, iProb)

This subroutine calculates the spatial distributed infiltration probability.

input

m,n	[integer]		dimensions of the spatial arrays
rfx, rfy	[integer]		maximum radius for plant effects on soil properties
kf	[integer]		
veg	[integer]	[m,n]	vegetation matrix
K0	[8-byte real]		
ie	[8-byte real]		
Kmax	[8-byte real]		
dx, dy	[8-byte real]		length scales of lattice

output

iProb	[8-byte real]	[m,n]	infiltration probability matrix

4.3.11 List Convolve

ListConvolve(base, kernel, convol, m, n, m1, n1)

input

m,n	[integer]	
m1,n1	[integer]	
base	[integer]	[m,n]
kernel	[integer]	[m,n]

output

convol	[]	[m,n]

4.3.12 Erosion

Erosion(discharge, topog, newflowdirns, flowResistance, m, n)

input

m,n	[integer]		dimensions of the spatial arrays
discharge	[integer]	[m,n]	discharge has units of $^{\mathrm{mm}}/_{\mathrm{year}}$
newflowdirns	[integer]	[m,n]	new flow directions
flowResistance	[8-byte real]	[m,n]	flow resistance; effective d_{40} grainsize in mm
topog	[8-byte real]	[m,n]	topography

output

topog	[8-byte real]	[m,n]	topography

Uses subroutines:
Lookupfdir(), cf. page 8

4.3.13 Splash

Splash(topog, veg, Dv, Db, m, n)

input

m,n	[integer]		dimensions of the spatial arrays
veg	[integer]	[m,n]	
topog	[8-byte real]	[m,n]	topography
Dv,Db	[8-byte real]		$^{\mathrm{m}^2}/_{\mathrm{kyr}}$

output

topog	[8-byte real]	[m,n]	topography

Uses subroutines:
Neighbours(), cf. page 12

4.3.14 Find holes

FindHoles(newtopog,holes)

input

`newtopog` [8-byte real] [:,:] topography

output

`holes` [8-byte real] [:,:]

Listing 1: a program listing could look like this; notice the language sensitive formatting

```
1  SUBROUTINE FindHoles(newtopog,holes)
2  IMPLICIT NONE
3
4  REAL*8, DIMENSION(:,:), INTENT(IN) :: newtopog
5  INTEGER, INTENT(OUT) :: holes
6
7  INTEGER :: m,n,i,j,k,l
8  m=SIZE(newtopog,1)
9  n=SIZE(newtopog,2)
10
11 DO i=2,m-1
12 DO j=2,n-1
13     holes=0
14     DO k=-1,1
15     DO l=-1,1
16         IF (newtopog(i,j) < newtopog(i + k, j + l)) THEN
17             holes = holes + 1
18         END IF
19     END DO
20     END DO
21     IF (holes.ge.8) THEN
22         holes = 1
23         RETURN
24     END IF
25 END DO
26 END DO
27
28 END SUBROUTINE FindHoles
```

Listing 1 shows, how code can be inserted into the document. With line numbers and Fortran specific code highlighting.

It is possible to refer to individual lines inside the listing with LaTeX commands `\label{}` and `\ref{}`, so references get updated if the code changes. For example line 16 in listing 1, where the first `IF`-condition begins.

The code in the listing could be loaded from an external file (for example the actual Fortran file).

4.3.15 Evaporation

Evaporation(veg, eTActual, bareE, store, tsteps, rcx, rcy, kc, dx, dy, te, pbar, Psb, Psv, Emax)

This subroutine determines the transpiration by idividual plants as well as the bare soil sites and removes water from storage.

input

`veg`	[integer]	[:,:]		
`eTActual`	[integer]	[:,:]		
`bareE`	[integer]	[:,:]		
`store`	[integer]	[:,:]		
`tsteps`	[integer]			
`rcx, rcy, kc`	[8-byte real]			
`dx, dy`	[8-byte real]			
`te`	[8-byte real]	t_e	[T]	length of a time step in evap calcs nanu: (dry period of the year) [is this right?]
`Emax`	[8-byte real]	T_{max}	[L T^{-1}]	maximum plant transpiration

output

`store`	[integer]	[:,:]	
`eTActual`	[integer]	[:,:]	
`bareE`	[integer]	[:,:]	

Uses subroutines:
`TwoDRandPos()`, cf. page 6

t_e is defined as $t_e = 1 - t_r$, with t_r ... length of rain period

$T_{max} = \beta_t D/t_e$ with β_t ... proportion of the mean annual rainfall that is potentially able to be transpired subject to physiological and environmental constrains.

T_{max} by Mcgrath et al. (2012) was estimated as the avarage potential transpiration rate from the Penman Monteith equation and an assumed leaf area index to about $5\,\mathrm{mm\ d^{-1}}$

4.3.16 Neighbours

`Neighbours``(order, posij, dom, neighbs)`

input

`order`	[integer]	
`posij`	[integer]	[2]
`dom`	[integer]	[2]

output

`neighbs` [integer] [Nanu: (order*2+1)**2,2 [as formula?]]

4.3.17 LSDs

`LSDs``(order, posxy, topog, m, n, lsdList)`

This function returns the matrix positions:

LSD1: the position of the neighbouring cell with the steepest slope downhill

LSD2: the position of the neighbouring cell with second steepest slope adjacent LSD1

otherpos: the position of the other neighbouring cell the mirror reflection about LSD1 of LSD2

input

m,n	[integer]	
posxy	[integer]	[2]
topog	[8-byte real]	[m,n]

output

lsdList	[integer]	[3,2]

Uses subroutines:
Neighbours(), cf. page 12
RotateArray(), cf. page 13

4.3.18 Array rotation

RotateArray(list, m, n, leftorRight)

input

m,n	[integer]	
list	[integer]	[m,n]
leftorRight	[integer]	

output

list	[integer]	[m,n]

4.3.19 Pos1D

Pos1d(list, m, n, match, rownum)

input

m,n	[integer]	
list	[integer]	[m,n]
match	[integer]	[n]

output

rownum	[integer]	[m]

4.3.20 GD8 fow directions

GD8(topog, flowdirns, m, n)

input

m,n	[integer]	
topog	[8-byte real]	[m,n]

output

flowdirns	[integer]	[m,n]	flow directions

Uses subroutines:
`makeOrds()`, cf. page 15
`Pos1d()`, cf. page 13
`endShift()`, cf. page 15
`LSDs()`, cf. page 12
`fdirLookup()`, cf. page 14
`RotateArray()`, cf. page 13

4.3.21 New GD8 flow directions

NewGD8(topog, lakes, flowdirns, m, n)

Calculates flow directions following the GD8-algorithm of Paik (2008)

input

m,n	[integer]	
lakes	[integer]	[m,n]
topog	[8-byte real]	[m,n]

output

flowdirns	[integer]	[m,n]	flow directions

Uses subroutines:
`makeOrds()`, cf. page 15
`Pos1d()`, cf. page 13
`endShift()`, cf. page 15
`LSDs()`, cf. page 12
`fdirLookup()`, cf. page 14
`Neighbours()`, cf. page 12

4.3.22 fdirLookup(dirnxy, idirn)

fdirLookup(dirnxy, idirn)

input

dirnxy	[integer]	[2]

output

idirn	[integer]

4.3.23 Array sort

qsortd(x, ind, n, incdec)

This subroutine uses an order $n \cdot \log(n)$ quick sort to sort a real (double precision/8-byte) array $x(n)$ into increasing order.

input

`x(n)`	[8-byte real]	vector of length `n` to be sorted
`n`	[integer]	length of the array `x(n)`
`incdec`	[integer]	if positive the ind is returned so values decreasing order
`incdec`	[integer]	

output

`ind(n)`	[integer]	vector of length $\geqq$ `n`; sequence of indices $1, \ldots, n$ permuted in the same fashion as x would be: $y(i) = x\,(ind(i))$

`ind` is initialized to the ordered sequence of indices $1, \ldots, n$, and all interchanges are applied to `ind`. `x` is devided into two portions by picking a central element t. The first and last elements are compared with t, and interchanges are applied as necessary so that the three values are in ascending order. Interchanges are then applied so that all elements greater than t are in the upper portion of the array and all elements less than t are in the lower portion. The upper and lower indices of one of the portions are saved in local arrays, and the process is repeated iteratively on the other portion. When a portion is completely sorted, the process begins again by retrieving the indices bounding another unsorted portion.

Note: IU and IL must be dimensioned $\geqq \log(n)$ where $\log$ has base 2.

Credit goes to Robert Renka Oak Ridge Natl. Lab.

4.3.24 endShift

endShift`(arr, rownum, mn, n)`

input

`rown`	[integer]	
`n`	[integer]	
`mn`	[integer]	
`arr`	[integer]	[mn,n]

output

`arr`	[integer]	[mn,n]

4.3.25 makeOrds

makeOrds`(topog, ords, m, n)`

input

`m,n`	[integer]	
`topog`	[8-byte real]	[m,n]

output

`ords`	[integer]	[size(topog),2]

Uses subroutines:
`qsortd()`, cf. page 14

4.3.26 Vegetation Change

VegChange`(veg,m,n,vegmax, storEmerge, etPersist, useStorEmerge, store, actualET,isGrow)`

This subroutine implements the simple algorithm to change vegetation/bare soil status and update biomass

input

`m,n`	[integer]				
`etPersists`	[integer]	T_c	$[\mathrm{L\,T^{-1}}]$	annual transpiration rate over which plants start to grow (transpiration threshold for carbon assimilation)
`vegmax`	[ingeger]	b_{max}		maximum biomass
`isGrow`	[integer]			
`useEmerge`	[logical]			flag denotes whether to use random collonisation pc or storage based storEmerge
`storEmerge`	[integer]	w_c	$[\mathrm{L}]$	water storage threshold triggering plant emergence at bare sites
`veg`	[integer] [m,n]			
`store`	[integer] [m,n]			
`actualET`	[integer] [m,n]	T_a	$[\mathrm{L\,T^{-1}}]$	the spatial distribution of actual evapotranspiration

output

`veg`	[integer]	[m,n]
`store`	[integer]	[m,n]
`actualET`	[integer]	[m,n]

Note: there is no variable for $\Delta\tilde{b}$, the normalized vegetation growth delta. It is simply set to nanu: 1. [1 is not consistend with the following text! And maybe we should make this an input variable.]

$$\Delta\tilde{b} = \frac{\Delta b}{b_{max}}$$

with Δb ... annualized avarage growth rate of plants. Mcgrath et al. (2012) used $b_{max} = 2\,\mathrm{kg\ m^{-2}}$ and $\Delta\tilde{b} = 0.1$ or rather $\Delta b = 0.2\,\mathrm{kg\ m^{-2}\ yr^{-1}}$

nondimensional threshold for plant emergence:

$$\tilde{w_c} = \frac{w_c}{\Delta x}$$

4.4 Customizability

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A Appendix