Modelling spread of Bluetongue in Denmark: The code.

Græsbøll, Kaare

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Kaare Græsbøll

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This technical report was produced to make public the code produced as the main project of the PhD project by Kaare Græsbøll, with the title: "Modelling spread of Bluetongue and other vector borne diseases in Denmark and evaluation of intervention strategies”.

1.1 The model

The main aim of the PhD thesis the code presented in this Technical report refer to, was to create a simulation model to predict the spread of Bluetongue and other vector borne diseases should they be introduced in Denmark. This model is presented in a publication with the title: "Simulating spread of Bluetongue Virus by flying vectors between hosts on pasture.” [1] Which has been preliminary accepted for publication in Scientific Reports, and it is recommended to read this report in conjunction with the article. Mathematical expression and parameter values are not included in this report, but are to be found in the article.

The program code presented is for the case of Bluetongue Virus with cattle as hosts and biting midges as vectors. Bluetongue Virus (BTV) is a non-contagious infectious disease that infects ruminants. In Denmark the primary ruminant of concern is cattle in which the disease causes relative mild symptoms, but do
reduce milk yield and increase the risk of spontaneous abortions. In certain breeds of sheep BTV can have a very high mortality, and therefore the disease is considered notifiable by the OIE. Bluetongue does not transmit directly between ruminants but requires to pass through a blood-sucking vector. Inside the vector BTV needs to replicate to a certain level and make it from the gut to saliva glands. This process is very sensitive to temperature and cannot be completed if the vector is at temperatures below 13°C. Therefore we take in meteorological data to calculate the extrinsic incubation period (EIP) a.k.a. the incubation time in the vectors.

What especially differentiates the model presented in this report with previous models on vector borne spread is that hosts can be distributed onto pasture areas. We wanted to create a more process oriented approach so that the parameters describing spread of disease relates directly to parameters describing flight patterns of vectors. For a more detailed description of the reasons to choose this particular model type see the PhD thesis.

The model share in-herd dynamics described in Gubbins (2008) [2] and Szmaragd (2009) [3] (Figure 1.1), while the between herd model was presented in Græsbøll (2012) [1] (Figure 1.2). Vaccination was modeled on UK data in a collaboration with the Pirbright Institute presented in Græsbøll (2012b) [4] using vaccination as described in Szmaragd (2010) [5].
1.1 The model

Figure 1.1: The viraemia of the hosts is described by an extended Susceptible Exposed Infectious Recovered (SEIR) model (left), and the vectors are described by an extended SEI model (right). All movements between the stages in the model are governed by the probabilities listed in Græsbøll (2012) [1], in the code most parameters are defined in gdata (section 2.2) or read in from the input.txt file (section 2.6.1).
Figure 1.2: Movement of vectors between herds are described either as active flight or passively carried by wind. This can be interpreted by 2D density distributions. (Left) probability density when vectors are moving by active flight to neighboring areas (arbitrary length scale, darker colors are equivalent to higher probability). (Right) probability density when vectors are carried by wind (arbitrary length scale). Mathematical expression can be found in Græsbøll (2012) [1].
The code was generated with an eye for speed, and alone for this reason the program was twice rebuild from scratch. The main issue with speed relates to the number of vectors: The number of vectors in high seasons is as many as 5,000 vectors per host. Given that there are approximately 1.7 million cattle in Denmark, this round up to almost 10 billion vectors, each need potentially be modeled for flight. This high number is never realistically reached, and optimizing for speed is therefore mainly a problem of best identifying relevant vectors to move. This is primarily achieved by keeping a list of all vectors and hosts with the disease, and only perform relevant operations: viraemia, movement, death, etc. on these animals. In the program this is handled by two lists that cross-reference to each other and to the map. Using a list proved much faster (at least a factor of ten) than just having vectors and host located in a grid matching the map and scanning across areas looking for animals with disease.

The code is structured with a control file `dk.f90` which then call 13 other modules to do as explained in the following sections as listed below (In parenthesis the section in appendix where to locate the code):

2.1 `dk.f90` (A.1) Determines the overall structure of the simulation.

2.2 `gdata.f90` (A.2) Defines the global data available to all modules.
2.3 initialize.f90 (A.3) Initialises many of the variables and arrays.
2.4 functions.f90 (A.4) Collates repeated functions.
2.5 iohosts.f90 (A.5) Reads in pasture maps.
2.6 iomodule.f90 (A.6) Initialization of pasture, farms, etc.
2.7 host.f90 (A.7) Reads input from the input.txt file.
2.8 temperatures.f90 (A.8) Handles temperature data.
2.9 makemap.f90 (A.9) Distributes hosts onto pasture.
2.10 viraemia.f90 (A.10) Emulates the viraemia of hosts and vectors.
2.11 windy.f90 (A.11) Handles wind data.
2.12 midge.f90 (A.12) Does the active and passive movements of vectors.
2.13 bite.f90 (A.13) Transmission of disease between vectors and hosts.
2.14 errorhandl.f90 (A.14) Various checks of the code.

Please note that section A.15 contains a full list of all modules and subroutines. Some parts of the code have been omitted to increase the ease of the read, these parts are mainly lines of codes that determines events when running in certain test modes of the program. However there are also omitted reallocation statements that handles sizes of arrays, these were omitted mostly due to space considerations. For a fully functional copy of the code please contact the author. The version number of the code presented is 9.7.4.

2.1 dk.f90 (A.1)

The main control file calls the subroutines that handles everything. The program is structured in this way because it makes it easy to turn subroutines on and off, which is very convenient in the test phase, and when testing different scenarios with regards to e.g. vaccinations or different countries. The code here presented contains two loops in dk.f90, one ’repeat’ which is simple replicates of the simulations, and one ’day’ that goes from day one to the designated ’end-day’. When running sensitivity analysis extra loops can be added to control parameters outside these two loops. Furthermore the control file writes much of the output to file. Often it can be desirable to handle output in a separate module, I chose otherwise because the day-counter is in dk.f90 it is very convenient to write output from this loop.
As the program is build using the module functionality of Fortran 90 it is advantageous to define the global data arrays in a module which is then called by all other modules. Structuring data in this way ensures that this global data is permanently in the computer memory and only in one copy. Using a module to state global data also eliminates the need to move data between subroutines, or call it explicitly. This is very nice if much data is to be moved. However, this do comes on the expense of the detailed knowledge of what goes in and out of the specific subroutines. Thus it sometimes becomes tricky to keep track of all variable names, I sincerely recommend using the `implicit none`, and also keep a separate file which contains names of the most important variables and arrays and their structure. Here I present parts of my own ”variable list”, both as an example, but also to ease the read of the code. The number of parenthesis after a variable indicates the dimensionality of the array, so that none = scalar, () = vector, ()() = matrix, and so on. Variable inside [ ] indicates optional variables. the [rand] indicates that variables are only use when generating fields at random.

```plaintext
=== List of variables ===================

hosts(y)(x)(#C,C_id,[#S,S_id,]M_id) the spatial map linking to the list
csick_loc (C_id)(y,x,M_id,#H,SEIR) list of infected cattle
ssick_loc (S_id)(y,x,M_id,#H,SEIR) list of infected sheep
msick_loc(M_id)(y,x,C_id,#C,[S_id,#S,]#H,T_id,SEIR) list of infected midges

#C, #S, #M number of cattle, sheep, midges at a given location
#H = #C + #S total number of hosts at a given location

C_id, S_id, M_id the ID number to cross reference lists

=== gdata.f90 ===

−integer−

xsize number of cells in x direction
ysize number of cells in y direction
mstages number of boxes used to emulate midge stages
ios input/output error status
xstart x value in cells of start of epidemic
ystart
msick
n_farms
nmax
nmean
input_type
area_sel
infherds
fly_c
day
m_var
mbboxes
mbij
h_var
a_fly
a_msick
host_types
fly()
msick_loc()
hstages()
mth()
hsick()
n_hosts()
hosts()
csick_loc()
csick_loc_com()
ssick_loc()
ssick_loc_com()
hsick_com()
a_hsick()
a_hsick_c()
mk
pi
loclen
mrec
wile
mmort
sizefac
temperature
biterate
flytime
2.2 gdata.f90 (A.2)

midgfly  fraction of midges that fly away from hosts
midgestay  fraction of midges that stay where no hosts
ave_dist  average distance between cells with hosts
meaninf  mean number of infected hosts per affected cell
vac_cov  fraction of hosts immune from vaccination
wind_s  wind speed in current cell
wind_a  angle of the wind in current cell
mbjr  real value of number of boxes to jump when emulate mboxes
hrec()  1/days for hosts to recover from infection
probtrans mh()  probability of transmission midge to host
probtrans hm()  probability of transmission host to midge
hosts outside()  percentage hosts outside

gdata.f90 also contains statements to turn host movement, movement restriction and a debugging mode (debugging statements have though mostly been removed from the displayed code) on and off.

Additional subroutines included are also primarily connected to the start-up of the program.

2.2.1 init (A.2.1)

Defines many of the parameters characterizing which disease and the effect on specific hosts. These statements are though somewhat obsolete as they are also read in from the input.txt file (section A.6.2). But some are needed to initialize the size of certain data arrays.

2.2.2 redistribute (A.2.2)

This subroutine reset all hosts and vectors arrays to the starting setup. This section is used for test runs when it is not desirable to resample all hosts onto pasture at every repetition.

2.2.3 seeed (A.2.3)

The seeed subroutine ensures that the random seed is indeed random. (Trivia: Seeed is also a name of one of the author’s favorite German bands.)
2.2.4 alloc_cphid (A.2.4)

This subroutine allocate cph numbers to all pasture, so that hosts can be tracked back to their owners.

2.3 initialize.f90 (A.3)

The Initialize module in its full contains initialization of epidemic for both Denmark and the UK, and also the definition of the UK vaccination roll-out plan. Here I have only included the initialization of the Danish epidemic.

2.3.1 init_inf (A.3.1)

It is possible to initiate using infected hosts or infected vectors. Here we also determine the area of first infection.

2.4 functions.f90 (A.4)

The functions module contains functions used throughout the program, but also subroutines to collect data and distribute flying vectors. From the original code some subroutines have been removed. The removed pieces of code did reallocation of arrays and error checks.

2.4.1 BINV (A.4.1)

This function approximates a draw from a binomial distribution. Fortran 90 has only a call to a uniform random distribution. The simple solution would be to do Bernoulli trials, however this method is significantly faster especially when the number of draws, $n$, is large and the probability, $p$, low. This combination of $n$ and $p$ is often fulfilled in the code given that there are often many vectors but transmission probability is very low. The algorithm was taken from Kachitvichyanukul and Schmeiser (1988) [6]. In this implementation the approximation crashes somewhere above $np = 500$ (probably due to rounding to zero), therefore for $np > 500$ the algorithm returns $np$. When running within
reasonable disease parameter and vector abundance this cutoff is almost never in use.

2.4.2 viraspread (A.4.2)

viraspread simply calculates the maximum distance virus has traveled from the starting point.

2.4.3 herd_inf (A.4.3)

This subroutine reports the number of currently infected herds and the prevalence in the herds.

2.4.4 flysort/flysortm (A.4.4)

When implementing dispersal of vectors, dispersing vectors was assigned to a temporary array so that the same vector was not able to fly more than once (see section 2.12). The two modes (active and passive) of vector dispersal can run with the temporary array being either a list or a matrix mode depending on the expected number of flying vectors. The subroutines flysort and flysortm distributes vectors from the temporary array (list and matrix respectively) and makes sure that all indexing arrays are updated.

2.5 iohosts.f90 (A.5)

Until version 9.6 of the program pasture distribution was read in from pre-made files using the read_mark_blocks subroutine. These pre-maps were very large, and it was not feasible to store the number needed to ensure proper sampling. However they did load faster than generating new maps for every run, so when doing test runs it was often used. The o part of iohosts.f90 is represented by subroutines find_herds and find_farms designed to make maps of the spread.
2.5.1  read_mark_blocks (A.5.1)

Reads in pasture data from files and distribute hosts onto these pasture areas. Pasture data for Denmark comes with a percentage of grass, therefore the program tries to distribute hosts onto pasture with high grass percentage first. It is also defined how many cattle per hectare that is maximum allowed.

2.5.2  find_herds/find_farms (A.5.2)

Outputs infected herd/farm locations to file.

2.6  iomodule.f90 (A.6)

This module was prematurely named as an io module, considering that it only does input.

2.6.1  read_inputfile (A.6.1)

To avoid numerous recompiles and to ease use for other users an input.txt was constructed which contains most of the parameters the program needs to run. read_inputfile reads and checks that input file. It also generate some parameters if the input file specified some random distribution. An example of the input file is included in section A.6.2.

2.7  host.f90 (A.7)

This module contains the subroutine to handle host movements.

2.7.1  host_move (A.7.1)

Host movements in the model are modeled by use of a transmission kernel. The kernel is fitted to data from "The Knowledgecenter of Agriculture, Dairy &
Cattle farming” who tracks all movements of cattle in Denmark. Ideally a more process oriented network analysis should form the basis of movements in future models. However, using this simple kernel approach showed very little influence of cattle movement on the output of the model, so I do not believe that this approximation does much difference to the model.

2.8 temperatures.f90 (A.8)

This module handles temperature related subroutines. Specifically the interpolation from daily to hourly temperature and mapping temperature stations so that herds share temperatures with the spatially nearest data point. From the original code was deleted subroutines which handles temperatures for UK, these where similar in function, and mostly differed because the structure of input data differs.

2.8.1 temp_var_h (A.8.1)

Many of the parameters in this model are nonlinear with relation to temperature and most have cutoffs whereunder values go to zero. E.g. the Extrinsic Incubation Period (EIP) have a cutoff at 13.5°C so if the daily mean temperature is below this value virus cannot replicate inside vectors. However it is possible that a part of the day has temperatures above cutoff, and in these periods virus should be able to replicate. To emulate this we interpolate from daily minimum and maximum temperatures using a sinusoidal function to approximate hourly temperature data.

2.8.2 read_temp_id (A.8.2)

The temperature data was provided by the Danish Meteorological Institute (www.dmi.dk) from 39 stations across Denmark. Data was processed for another project regarding Bluetongue (www.nordrisk.dk) where data was interpolated to a grid of 25 by 25 km. To increase the speed of the program a map of same resolution as the pasture map was made which indicate which temperature grid point the pasture should take temperature data from. This subroutine reads this pre-made map.
2.9  makemap.f90 (A.9)

This module contains the subroutine to make the grid cells (mark blocks) that represent the range vectors can locate hosts within.

2.9.1  make_mark_blocks (A.9.1)

While the size of the grid cells in the simulation represents the vectors ability to locate hosts, these are also pasture areas. This subroutine collect the input data with regards to which pasture areas are owned by which farmers, and how much cattle are owned by the individual farmer. Cattle are then randomly distributed onto pasture owned by the farmers according to criteria given in the input.txt file.

2.10  viraemia.f90 (A.10)

The viraemia.f90 module deals with the viraemia of hosts and vectors.

2.10.1  host_viraemia (A.10.1)

This subsections moves the infected hosts through the stages in the SEIR model (figure 1.1).

2.10.2  midge_viraemia (A.10.2)

This subsections moves the exposed vectors through the exposed stages (figure 1.1). The code starts by handling the cases where all exposed and infectious vectors have moved away. Then runs through the list of exposed/infected midges updating the parameters according to temperature, and moving them through the states or killing them. In the end the code handles the case where all exposed and infectious vectors have died. I have left in some out-commented code that claims to ensure constant amount of midges, this is a remnant from when the code ran with a fixed amount of midges, so all midges having died were replaced in the susceptible stage. However, when number of midges became variable on a daily and seasonal basis, the interpretation of number of midges became
equivalent to the number of susceptible midges. This was done because adjusting
the total number of midges would be more computationally demanding than the
out-commented line, and would also require further assumptions. An example:
we sample daily between 1 and 5000 midges, day one there is 5000 midges, and
we get 10 exposed midges, the next day we sample that there should be 1 midge.
If this number is not assumed to be the susceptible number, we need to consider
how to handle the 10 exposed midges from yesterday.

The observant reader might also have noted that the code seems to have 40
stages for the vectors, which is a lot different from the 11 as described in the
theory section of Græsbøll (2012) [1]. From hereon the 40 partitions will be
referred to as boxes to differentiate from the stages described in the theory.
When this code was initially written the number of stages was only given as
an interval, and while e.g. Gubbins (2008) [2] handled this by assigning the
number of stages for the EIP to each farm, this could not be achieved in this
model because vectors move around, and how to handle a vector in stage four
out of seven when it arrives at an area with 11 stages? This was solved by
emulating stages using the 40 boxes. To exemplify: if there are ten stages at a
given location (and for a given temperature) the vectors will jump four boxes
forward each time we evaluate the viraemia. In this implementation we can
think of the boxes as each representing 2.5% of the completion of EIP. This
implementation allows for vectors to move between areas with different number
of stages, and number of stages can also vary with temperature if needed. If the
number of boxes divided by the number of stages is not an integer, the vectors
will be distributed to the nearest boxes in proportions according to the decimal.

2.11 windy.f90 (A.11)

The windy module handles wind in the code.

2.11.1 wind_data (A.11.1)

Wind is drawn from a random distribution. In the code there are some out-
commented examples of how to generate anisotropic winds.
2.12  midge.f90 (A.12)

The module midge handles the movement of midges (vectors). Most importantly for the speed of the code, only vectors with the disease are allowed to move. Movement is designed to be handled in two different ways depending on the number of vectors to handle. When dealing with a small epidemic, every vector move is recorded into a list. When many vectors are flying all over the simulation box, the program can use a temporary matrix were all movements are subscribed to. The different modes are subsequently handled by the flysort/flysortm routines A.4.4, which places the flying vector in their landing areas. Parts of the code is out-commented this mostly different ways of handling vectors that flies outside the simulation box. The opted mode is that flights ending outside the simulation box is canceled. Out-commented modes are flights terminates at the edge, or flights outside box means instant dead.

2.12.1  midge_local (A.12.1)

Local flight is simulated by assuming a Gaussian random walk. To generate coordinates the Box-Muller algorithm is utilized [7].

2.12.2  midge_wind (A.12.2)

Midges carried by wind also have coordinates generated using the Box-Muller algorithm [7].

2.13  bite.f90 (A.13)

The bite module handles the transmission of virus between vectors and hosts. In the subroutines there are a lot of code which handles the different index arrays when bites leads to transmission. There is also different ways of handling vaccination included.
2.13.1 inf_hosts (A.13.1)

In this subroutine hosts becomes exposed to the virus by bites from infectious midges.

2.13.2 inf_midges (A.13.2)

In this subroutine susceptible vectors becomes exposed to the virus by biting infectious hosts. Notice that it is emulated that the titres of virus in blood is different in different stages of the disease, as has been seen in experimental data [8].

2.14 errorhandl.f90 (A.14)

In the end I show parts of the testing algorithm. When using index lists it becomes very important to make sure that these list cross-reference exactly so that information is not lost or misinterpreted.

2.14.1 findmidges (A.14.1)

Test if midge IDs are correctly handled in the host list.

2.14.2 findhosts (A.14.2)

Test if host IDs are correctly handled in the host and vector lists.
Following is the source code for version 9.7.4 of the program. This version is only a slight alteration from the version 9.7.2 which was used to produce data in paper [1]. It is also very little difference on this code and the code used to produce paper [4]. This print of the code have been edited from the original to make reading easier. For example all statements relating to the parallelization of the code have been excluded. Various debugging statements have also been deleted. This code does only represent one simulation of Denmark. For real use additional loop were introduced to do sensitivity analysis.

The subroutines are tabled in section A.15. Subroutines are therefore sectioned, which is not part of the original code.
A.1  dk.f90 (2.1)

**PROGRAM** dk ! simulate spread of btv in dk 2008

USE gdata
USE functions
USE initialize
USE iohosts
USE iomodule
USE host
USE temperatures
USE makemap
USE viraemia
USE windy
USE midge
USE bite
USE errorhandl

**IMPLICIT NONE**

INTEGER, PARAMETER :: ntemp=1,nrep=1,nrepeat=1
INTEGER :: i, j, k, h, l, m, temp, myrank, ierror, nproc, n
INTEGER :: init_count, iday, hsicko
REAL (mk) :: x, newdist
CHARACTER :: date*8, hour*10

CALL init
CALL read_inputfile

myrank=0

CALL DATE_AND_TIME(date, hour)
WRITE (*,'(a15,5(a2,a),a4)') 'Starting time: ', hour(1:2), ': ', &
  hour(3:4), ': ', date(7:8), '/ ', date(5:6), '− ', date(1:4)
WRITE (*,*) 'Start'
ENDIF

CALL seeed
CALL read_temp_id
endday=400
flyminit=700
init_count=0
repeat=0

vac_cov=0.0

DO repeat=1,nrepeat

DO inf_date=1,365

! call redistribute
! call read_mark_blocks
CALL make_mark_blocks
! call chr_start

DO day=1,endday

IF (day==inf_date) CALL init_inf

!---- update variables dependent on temperature ----
CALL temp_var_h

!---- viraemia for hosts ---- hosts never dies of BT
CALL host_viraemia
!CALL checkcsick

!---- viraemia for midges ----
CALL midge_viraemia

IF (day==endday) CALL findhosts
CALL checkmsick
! call findmidges

!---- wind determination ----
CALL wind_data

!---- midge local spread ----

IF (day==flyminit) DEALLOCATE(fly)
IF (day>=flyminit) flym=0
CALL midge_local
IF (day<flyminit) CALL flysort

!CALL checkmsick
!--- midge wind spread ---
CALL midge_wind
IF (day<flyminit) THEN
   CALL flysort
ELSE
   CALL flysortm
ENDIF

!CALL checkmsick

!--- host movement ---
IF (hostsmove) CALL host_move

!=== BITE ===

!--- infection of hosts ---
CALL inf_hosts

!--- infection of midges ---
CALL inf_midges

!--- check whether lists contain all virus
CALL findmidges
CALL findcattle

IF (hsick(1)>0) THEN
   iday=−1
   DO n=1,hsick(1)
      IF (n>hsicko) iday=day
      WRITE (29,'(6(i5,x))') &
      & n,day,SUM(csick_loc(n,6:10)),SUM(csick_loc(n,5:11)),&
      & SUM(csick_loc(n,6:11)),iday
   ENDDO
   hsicko=hsick(1)
ENDIF

newdist=viraspread()
infcph=0
CALL herd_inf
!CALL find_farms
!CALL find_clinical_signs !— must be within the day do loop
!if (inf_date == 180) CALL spreadkernel

WRITE(23,'(i7,3(x,i6),3(x,f7.2),f5.2)') &
& SUM(hosts(:,:,1)),infeph,hsick (1), hsick (2),msick,&
& SUM(csick_loc(1:hsick(1),6:11)),&
& SUM(ssick_loc(1:hsick(2),6:13)),&
& SUM(msick_loc(1:msick,2+m_var:2+m_var+mstages)),&
& SUM(msick_loc(1:msick,2+m_var+mstages)),&
& newdist, &
& meaninf,meanpinf,vac_cov!,clincph
flush (23)

ENDDO !— day
ENDDO !— inf_date
!CALL spreadkernel

ENDDO !— repeat

CALL DATE_AND_TIME(date,hour)
WRITE (*,'(a10,5(a2,a),a4)') 'End time: ',hour(1:2),': ',&
& hour(3:4),': ',hour (5:6), ' ',date (7:8), '/',date (5:6), ' —',date (1:4)
WRITE (*,*)'errorcounter: ',errorcounter
WRITE (*,*)'initcounter: ',init_count
ENDIF

END PROGRAM
A.2 gdata.f90 (2.2)

```fortran
MODULE gdata
IMPLICIT NONE

INTEGER :: xsize,ysize,mstages,ios,xstart,ystart,msick,inf_date
INTEGER :: nmax,nmean,input_type,area_sel,infherds,endday
INTEGER :: fly_c,day,m_var,h_var,infcph,repeat,errorcounter
INTEGER :: a_fly,a_msick,host_types,mth,ht,max_id_temp,ukinit,flyminit

INTEGER :: clin_sign(125118),clinph

INTEGER, ALLOCATABLE :: fly(:,),msick_loc(:,),rollout(:)
INTEGER, ALLOCATABLE :: hosts(:,,:),csick_loc(:,),county(:)
INTEGER, ALLOCATABLE :: csick_loc_com(:,),mboxes(:,),mbjji(:,),flym(:,,:)
INTEGER, ALLOCATABLE :: ssick_loc(:,),cattle(:,,:),cphid(:,)
INTEGER, ALLOCATABLE :: csick_loc_com(:,),id_temp(:,),vac_id(:,)

INTEGER, PARAMETER :: mk=KIND(1.0E0),mht=2

INTEGER :: hstages(mht),hsick(mht),n_hosts(mht)
INTEGER :: hsick_com(mht),n_farms(mht)
INTEGER :: a_hsick(mht),a_hsick_c(mht)
INTEGER :: LocInitO(7,2)
! integer :: mlpar1,mlpar2

REAL, PARAMETER :: pi=3.1415926535897932_mk

REAL(mk) :: loclen,wile,sizefac,temperature
REAL(mk) :: flytime,midgefly,midgestay,meanpinf
REAL(mk) :: ave_dist,meaninf,vac_cov,wind_s,wind_a
REAL(mk) :: efficacy

REAL(mk) :: hmove(mht),hmovef(mht)
REAL(mk) :: hrec(mht),probrob_trans_mh(mht),probrob_trans_hm(mht),hosts_outside(mht)
REAL(mk) :: tfp(mht)

REAL(mk), ALLOCATABLE :: mrec(:,),biterate(:,),mbjr(:,),mmort(:,),tmin(:,),tmax(:,)

! logical :: hostsmove=.TRUE.
LOGICAL :: hostsmove=.FALSE.

LOGICAL :: movingrestrictions=.FALSE.
```
! logical :: testmode=.TRUE.
LOGICAL :: testmode=.FALSE.

! logical :: testmodef=.TRUE.
LOGICAL :: testmodef=.FALSE.

LOGICAL :: oo_transkernel=.FALSE.

LOGICAL, PARAMETER :: varmth=.FALSE. ! variable amount of midges
LOGICAL, PARAMETER :: varmthdk=.TRUE. ! variable amount of midges dk style

LOGICAL :: varvac=.FALSE. ! variable vaccination cover

CONTAINS

A.2.1 init (2.2.1)

SUBROUTINE init !--- initialise parameter values
!--- mostly obsolete due to input.txt
IMPLICIT NONE

INTEGER :: mit
mstages=40
hstages(1)=5
hrec(1)=REAL(1./20.6,mk)
wile=0.5_mk
probtrans_nh=0.9_mk
probtrans_hm=0.1_mk
sizefac=0.1_mk
flytime=0.25_mk
midgestay=0.5_mk
loclen=0.3_mk/sizefac/0.675_mk
hosts_outside=0.9
vac_cov=0.
errorcounter=0
!m_var=3+2+ht
h_var=4
efficacy =1.
tfp(1)=60.

!--stages of infection to mimic Gamma–dist.
! Cattle Recovery probabilities 1/days
!—width to length scale in wind spread cone
!—probability of transmission midge -> host
!—probability of transmission host -> midge
!—cell side length in km
!—length of flight time
!—fraction of midges that fly with the wind
!—fraction of midges that stay where no cattle
!—local length scale for M random walk
!—fraction of farmers who put cattle on pasture

!— must be defined in iomodule
hmove = 0.001 ! daily probability of moving a host
hmovef = 0.2

!---SHEEP
hstages(2)=7
hrec(2)=REAL(1./16.4,mk) ! Sheep Recovery probabilities 1/days
tfp(2)=14.

ios=0
a_fly=2000
a_msick=10000
a_hsick=100
a_hsick_c=1000
hsick=0
hsick_com=0
hsick=0
msick=0
clin_sign=0
clincph=0

OPEN (23,FILE='sick.dat',STATUS='replace',ACTION='write')
OPEN (29,FILE='afi.dat',STATUS='replace',ACTION='write')
OPEN (27,FILE='testing.dat',STATUS='replace',ACTION='write')
OPEN (28,FILE='testing2.dat',STATUS='replace',ACTION='write')
OPEN (21,FILE='/home/kagr/Desktop/Data/temperature/y2008dk.dat', STATUS='old', ACTION='read')
OPEN (62,FILE='inf_data.dat',STATUS='replace',ACTION='write')
OPEN (44,FILE='spread_data.dat',STATUS='replace',ACTION='write')

END SUBROUTINE init

!==============================================

A.2.2 redistribute (2.2.2)

SUBROUTINE redistribute ! ready to restart with same host distribution
IMPLICIT NONE

INTEGER :: i,j,cows,k
REAL(mk) :: x

hosts (:,:,2)=0
IF (host_types==1) hosts(:,:,3)=0
IF (host_types==2) hosts(:,:,4)=0

hsick(1)=0
csick_loc =0

msick=0
msick_loc=0

hsick_com(1)=0
csick_loc_com=0

clin_sign =0
clinph=0

IF (host_types>1) THEN
hsick(2)=0
hsick_com(2)=0
ssick_loc =0
ssick_loc_com=0
ENDIF

REWIND (21)

a_fly =2000
a_msick=10000

IF (allocated(fly)) DEALLOCATE(fly)
DEALLOCATE(msick_loc)

ALLOCATE(fly(a_fly,3))
ALLOCATE(msick_loc(a_msick,m_var+mstages+2))

fly =0
msick_loc=0

END SUBROUTINE
SUBROUTINE seeed !--- seed the random number generator
IMPLICIT NONE

INTEGER :: isize,idate(8)
INTEGER,ALLOCATABLE :: iseed(:)

CALL DATE_AND_TIME(VALUES=idate)
CALL RANDOM_SEED(SIZE=isize)
ALLOCATE( iseed(isize) )
CALL RANDOM_SEED(GET=iseed)
iseed = iseed + 1
iseed = iseed * (idate(8)−500) ! idate(8) contains milisecond
! iseed = 100 !-- non−random run
CALL RANDOM_SEED(PUT=iseed)

!PRINT *,iseed
END SUBROUTINE

SUBROUTINE alloc_cphid
IMPLICIT NONE

INTEGER :: n

ALLOCATE(cphid(ysize,xsize))

SELECT CASE (area_sel)
  CASE (4,5,8)
    OPEN (42,FILE=’/home/kagr/Desktop/Data/uk/fields/cphraster.dat’,&
       STATUS=’old’,ACTION=’read’)
  CASE (9)
    OPEN (42,FILE=’/home/kagr/Desktop/Data/uk/fields/cphraster2.dat’,&
       STATUS=’old’,ACTION=’read’)
END SELECT

END SUBROUTINE
CASE (10)
  OPEN (42, FILE='/home/kagr/Desktop/Data/uk/fields/cphraster5.dat', &
  &   STATUS='old', ACTION='read')
END SELECT

DO n=1,6
  READ (42,*)
ENDDO

DO n=1,ysize
  READ (42,*) cphid(n,:)
ENDDO

END SUBROUTINE alloc_cphid

END MODULE
A.3 initialize.f90 (2.3)

MODULE initialize ! the BT epidemic in different ways

CONTAINS

A.3.1 init_inf (2.3.1)

SUBROUTINE init_inf

USE gdata
USE functions
IMPLICIT NONE

INTEGER :: i,j,k,cows
REAL(mk) :: x

IF (.FALSE.) THEN
!==============================================
!−−−−−initiate start with cattle
!==============================================

ht=1
xstart=xsize/2
ystart=ysize/2
i=ystart
j=xstart

CALL seeed

DO WHILE (hosts(i,j,1)==0)
    CALL random_number(x)
    k=FLOOR(x*xsize*ysize)+1
    i=k/xsize+1
    j=MOD(k,xsize)+1
    ystart=i
    xstart=j
ENDDO

cows=hosts(ystart,xstart,1)

hsick(ht)=1
csick_loc =0
csick_loc (1,1:2)=(/ystart , xstart/)  
csick_loc (1,h_var+1)=MAX(cows−5,1)  
csick_loc (1,h_var+2)=5

msick=0  
msick_loc=0  

hsick_com(ht)=1  
csick_loc_com=0  

hsick_com(1,1:2)=(/ystart , xstart/)  
csick_loc_com(1,3)=0  

ENDIF

!============================================================================
!—- initiate start with midges
!============================================================================

xstart=NINT(50./sizefac)  
ystart=NINT(50./sizefac)  
i=ystart  
j=xstart

DO WHILE (hosts(i,j,1)==0)  
   i=i+1  
   ystart=i
ENDDO

hsick=0  

msick_loc =0  

ssick_loc =0  

msick=1  

msick_loc=0

hosts(i,j,1+2*host_types)=msick  

msick_loc(msick,1:2)=(/i , j/)  

msick_loc(msick,3:4)=(/ hosts(i , j ,2), hosts(i , j ,1)/)  

msick_loc(msick,5:)=0  

msick_loc(msick,3+2*host_types)=hosts(i,j,1)  

IF (host_types>1) THEN  
   msick_loc(msick,3+2*host_types)=msick_loc(msick,3+2*host_types)+hosts(i,j,3)  
   msick_loc(msick,5:6)=(/ hosts(i , j ,4), hosts(i , j ,3)/)
ENDIF

msick_loc(msick,m_var+mstages+2)=10
hsick_com=0
csick_loc_com=0
ssick_loc_com=0

END SUBROUTINE

END MODULE
MODULE functions ! contains functions used repeatedly
! OPEN— statements should be in 60’ties

CONTAINS

A.4.1 BINV (2.4.1)

!=== BINV simulates a draw from binomial distribution
!=== by V. Kachitvichyanukul and B.W. Schmeiser

FUNCTION binv(pp,n)
IMPLICIT NONE

INTEGER :: binv
INTEGER, INTENT(IN) :: n
DOUBLE PRECISION, INTENT(IN) :: pp

DOUBLE PRECISION :: p,q,s,a,r,u

p=pp

IF (pp>=1.) THEN
  binv=n
  !'print *,’Input error in functions:binv’
  RETURN
ENDIF

IF (pp>0.5) p=(1.-pp)

IF (p*n > 500.) THEN
  binv=NINT(p*n)
  IF (pp>0.5) binv=n−binv
  RETURN
ENDIF

IF (n==0) THEN
  binv=0
  RETURN
ENDIF

q=1.-p
s=p/q

a=REAL(n+1,KIND(1.0D0))*s
r=q**REAL(n,KIND(1.0D0))

CALL random_number(u)
binv=0

DO WHILE (u >= r .and. binv<n)

   u=u−r
   binv=binv+1
   r=(a/binv−s)*r

ENDDO

IF (pp>0.5) binv=n−binv
END FUNCTION

!====================================

A.4.2 viraspread (2.4.2)

FUNCTION viraspread()

USE gdata

IMPLICIT NONE

REAL(mk) :: viraspread
INTEGER :: i,j,h

viraspread=0._mk

DO ht=1,host_types
   DO h=1,hsick(ht)
      IF (ht==1) THEN
         i=csick_loc(h,1)
         j=csick_loc(h,2)
      ENDIF
      IF (ht==2) THEN
         i=ssick_loc(h,1)
      ENDIF
   END
j=ssick_loc(h,2)

ENDIF

viraspread=MAX(viraspread , sqrt(REAL(i-ystart)**2. + REAL(j-xstart)**2.))

ENDDO

viraspread=viraspread*sizefac

END FUNCTION

!===========================================================================

A.4.3 herd_inf (2.4.3)

SUBROUTINE herd_inf

USE gdata

IMPLICIT NONE

INTEGER :: k,h,i,j,cmi
REAL :: cpi

infherds=0
cmi=0

DO ht=1,host_types
   IF (hsick(ht)>0) THEN
      DO h=1,hsick(ht)
         IF (ht==1) THEN
            IF (csick_loc(loc(h,1)>0) THEN
               infherds=infherds+1
               cmi=cmi+SUM(csick_loc(h,h_var+2:(h_var+hstages(ht)+2)))
               IF (SUM(csick_loc(h,h_var+1:(h_var+hstages(ht)+2)))>0) THEN
                  cpi=cpi+SUM(csick_loc(h,h_var+2:(h_var+hstages(ht)+2)))&
                  & /REAL(SUM(csick_loc(h,h_var+1:(h_var+hstages(ht)+2)))
               ELSE
                  cpi=cpi+0.
               ENDIF
            ENDIF
         ENDIF
      ENDDO
   ENDIF
   IF (inf_date==170) WRITE (44,*) csick_loc(h,2),csick_loc(h,1),repeat
ENDIF

IF (ht==2) THEN
  IF (ssick_loc(h,1)>0) THEN
    infherds=infherds+1
    cmi=cmi+SUM(ssick_loc(h,h_var+2:(h_var+hstages(ht)+2)))
    IF (SUM(ssick_loc(h,h_var+1:(h_var+hstages(ht)+2)))>0) THEN
      cpi=cpi+SUM(ssick_loc(h,h_var+2:(h_var+hstages(ht)+2)))&
      & /REAL(SUM(ssick_loc(h,h_var+1:(h_var+hstages(ht)+2))))
    ELSE
      cpi=cpi+0.
    ENDIF
  ENDIF
ENDIF

IF (inf_date==170) WRITE (44,* ssick_loc(h,2),ssick_loc(h,1),repeat
ENDIF

ENDDO
ENDIF
ENDDO

meaninf=0.
meanpinf=0.
IF (infherds>0) THEN
  meaninf=REAL(cmi)/REAL(infherds)
  meanpinf=cpi/REAL(infherds)
ENDIF

END SUBROUTINE

!=================================================================

A.4.4 flysort/flysortm (2.4.4)

SUBROUTINE flysort

USE gdata

IMPLICIT NONE

INTEGER :: h,i,j
ht=host_types

DO h=1,fly_c
i=fly(h,1)
j=fly(h,2)

IF (hosts(i,j,1+2*ht)==0) THEN
  msick=msick+1
  IF (msick>=a_msick) CALL re_al_msick
  hosts(i,j,1+2*ht)=msick
  IF (host(i,j,2)/=0) csick_loc(hosts(i,j,2),3)=msick
  IF (ht>1 .and. host(i,j,4)/=0) ssick_loc(hosts(i,j,4),3)=msick
  msick_loc(msick,1:2)=(/i,j/)
  msick_loc(msick,3:4)=(/host(i,j,2),host(i,j,1)/)
  msick_loc(msick,3+2*ht)=hosts(i,j,1)
ENDIF
msick_loc(msick,m_var+1:)=0
ENDIF
msick_loc(hosts(i,j,1+2*ht),fly(h,3)) = &
& msick_loc(hosts(i,j,1+2*ht),fly(h,3)) + 1
ENDDO

END SUBROUTINE

!===================================

SUBROUTINE flysortm
USE gdata
IMPLICIT NONE

INTEGER :: h,i,j
ht=host_types

DO h=1,41
  DO j=1,xsize
    DO i=1,ysize
      IF (flym(i,j,h)==0) CYCLE
      IF (hosts(i,j,1+2*ht)==0) THEN
        msick=msick+1
        IF (msick>=a_msick) CALL re_al_msick
        hosts(i,j,1+2*ht)=msick
        IF (host(i,j,2)/=0) csick_loc(hosts(i,j,2),3)=msick
      ENDIF
    END DO
  END DO
ENDDO
IF (ht>1 .and. hosts(i, j, 4)/=0)  ssick $\_loc$ (hosts(i, j, 4),3)=msick
msick $\_loc$(msick,1:2)=(/i, j/)
msick $\_loc$(msick,3:4)=(/ hosts(i, j, 2), hosts(i, j, 1)/)
msick $\_loc$(msick,3+2*ht)=hosts(i,j,1)

IF (ht>1) THEN
  msick $\_loc$(msick,5:6)=(/ hosts(i, j, 4), hosts(i, j, 3)/)
  msick $\_loc$(msick,3+2*ht)=msick $\_loc$(msick,3+2*ht)+hosts(i,j,3)
ENDIF
msick $\_loc$(msick,m_var+1:)=0
ENDIF
msick $\_loc$(hosts(i, j,1+2*ht),m_var+1+h) = &
& msick $\_loc$(hosts(i, j,1+2*ht),m_var+1+h) + flym(i,j,h)

ENDDO
ENDDO
ENDDO

END SUBROUTINE flysortm

END MODULE
A.5  iohosts.f90 (2.5)

MODULE iohosts ! Distributes cattle from raster files

CONTAINS

A.5.1  read_mark_blocks (2.5.1)

SUBROUTINE read_mark_blocks

USE gdata
USE functions
IMPLICIT NONE

INTEGER :: ndata,ndata2
INTEGER :: n,i,hist (0:432)
INTEGER :: idump,j,indhi,indlow, field
INTEGER :: cpumapp,oldchr,count
INTEGER :: frommapnr,tomapnr,mapnr,nc,ns
INTEGER :: ncols,nrows,nodat
INTEGER :: trow,brow,lcol,rcol,location,tkpa,tmkpa

INTEGER, ALLOCATABLE :: map(:,),cpumap(:,),cpu(:,),chr2(:)
INTEGER, ALLOCATABLE :: chr(:,),cpun(:,),upc(:,),chk(:)
INTEGER, ALLOCATABLE :: pos2(:,),chk2(:)

REAL :: xllc , yllc , cellsize , rdump,dist,diste,ccpu,fwf
REAL :: totalarea , cattdens , x , cutoff , x

REAL, ALLOCATABLE :: area(:,),graes(:,),kvaeg(:,),kvaeg2(:)
REAL, ALLOCATABLE :: kpa(:,),totarea(:)

CHARACTER :: dump*14,temp*8,cdump*99,prename*54
CHARACTER, ALLOCATABLE :: unikblok(:)*9

CALL seeed

SELECT CASE (area_sel)

CASE (1,11:13) !—— Denmark without bornholm read from file ————
! maps 001—004 are with 100% cattle outside
! maps 101—104 are with 50% cattle outside
! maps 201—204 are with 0% cattle outside
CALL random_number(x)
mapnr=NINT((tomapnr-frommapnr+1)*x-0.5)+frommapnr
mapnr=MIN(mapnr,tomapnr); mapnr=MAX(mapnr,frommapnr)

IF (area_sel==1) WRITE (prename,'(a41,i3.3,a9)') &
& '/home/kagr/Desktop/Data/fields/cattle_dk/',mapnr,'dkmap.dat'

IF (area_sel==11) WRITE (prename,'(a41,i3.3,a10)') &
& '/home/kagr/Desktop/Data/fields/cattle_dk/',mapnr,'dkmap2.dat'

IF (area_sel==12) WRITE (prename,'(a41,i3.3,a10)') &
& '/home/kagr/Desktop/Data/fields/cattle_dk/',mapnr,'dkmap3.dat'

IF (area_sel==13) WRITE (prename,'(a41,i3.3,a10)') &
& '/home/kagr/Desktop/Data/fields/cattle_dk/',mapnr,'dkmap5.dat'

OPEN (1,FILE=prename,STATUS='old',ACTION='read')

READ (1,*) dump,ncols
READ (1,*) dump,nrows
READ (1,*) dump,xllc
READ (1,*) dump,yllc
READ (1,*) dump,cellsize
READ (1,*) dump,nodat_val

ysize=nrows
xsize=ncols
sizefac = cellsize /1000.

IF (allocated(hosts) .eqv. .false .) THEN
ALLOCATE(hosts(ysize,xsize,1+2*host_types))
ENDIF
hosts=0

DO n=1,nrows

READ (1,*) hosts(n,:,1)

ENDDO
CLOSE (1)
CASE (2) !--- lolland ---

OPEN (1, FILE='/home/kagr/Desktop/Data/fields/ubr_lol.dat', &
 &    STATUS='old', ACTION='read')
OPEN (11, FILE='/home/kagr/Desktop/Data/fields/check_lol.dat', &
 &    STATUS='old', ACTION='read')
OPEN (2, FILE='/home/kagr/Desktop/Data/fields/kvaegdata_lol.dat', &
 &    STATUS='old', ACTION='read')
!OPEN (3, file='cattle_lol.dat', status='replace', action='write')

ndata=452; ndata2=182
fwf=1./(92./182.) !-- fwf = 1/farms with fields

CASE (3) !--- jutland

OPEN (1, FILE='/home/kagr/Desktop/Data/fields/ubr_jut.dat', &
 &    STATUS='old', ACTION='read')
OPEN (11, FILE='/home/kagr/Desktop/Data/fields/check_jut.dat', &
 &    STATUS='old', ACTION='read')
OPEN (2, FILE='/home/kagr/Desktop/Data/fields/kvaegdata_jut.dat', &
 &    STATUS='old', ACTION='read')
!OPEN (3, file='cattle_jut.dat', status='replace', action='write')

ndata=5224; ndata2=1128
fwf=1./(863./1128.) !-- fwf = 1/farms with fields

CASE (5) !--- England farms

OPEN (1, FILE='/home/kagr/Desktop/Data/uk/EnglandFarms.txt', &
 &    STATUS='old', ACTION='read')

ysize=4880
xsize=5182

IF (allocated(hosts) .eqv. .false .) THEN
ALLOCATE(hosts(ysize,xsize,1+2*host_types))
hosts=0
ENDIF

DO n=1,95977

READ (1,'(2(i6,x),2(i5,x))') j, i, nc, ns
hosts(NINT(i/100.),NINT(j/100.),1)=nc
IF (host_types==2) hosts(NINT(i/100.),NINT(j/100.),3)=ns

ENDDO

CASE (6) !--- full Denmark ---------------

OPEN (1,FILE='/home/kagr/Desktop/Data/fields/maps/unikblokraster.txt',& & STATUS='old',ACTION='read')
OPEN (11,FILE='/home/kagr/Desktop/Data/fields/check.dat',& & STATUS='old',ACTION='read')
OPEN (2,FILE='/home/kagr/Desktop/Data/fields/kvaegdata.dat',& & STATUS='old',ACTION='read')

ndata=107118; ndata2=22092
fwf=1./(16641./22092.) !-- fwf = 1/farms with fields

CASE (7) !--- Denmark without bornholm

OPEN (1,FILE='/home/kagr/Desktop/Data/fields/ubr.dk-b.dat',& & STATUS='old',ACTION='read')
OPEN (11,FILE='/home/kagr/Desktop/Data/fields/check.dk-b.dat',& & STATUS='old',ACTION='read')
OPEN (2,FILE='/home/kagr/Desktop/Data/fields/kvaegdata.dk-b.dat',& & STATUS='old',ACTION='read')

ndata=81836; ndata2=21877
fwf=1./(15442./21877.) !-- fwf = 1/farms with fields

CASE (8:10) !--- ukpasture ---------------

! maps 201–204 are with 50% hosts outside 30% with resc 5
! maps 101–104 are with 25% hosts outside
! maps 001–004 are with 0% hosts outside

frommapnr=201
tomapnr=201

!-- read in cattle

CALL random_number(x)
mapnr=NINT((tomapnr–frommapnr+1)*x–0.5)+frommapnr
mapnr=MIN(mapnr,tomapnr); mapnr=MAX(mapnr,frommapnr)

IF (area_sel==8) &
& WRITE (prename,’(a34,i3.3,a11)’) & 
& ’/home/kagr/Desktop/Data/uk/fields’/mapnr,’ukmap_c.dat’

IF (area_sel==9) & 
& WRITE (prename,’(a34,i3.3,a12)’) & 
& ’/home/kagr/Desktop/Data/uk/fields’/mapnr,’ukmap_c2.dat’

IF (area_sel==10) & 
& WRITE (prename,’(a34,i3.3,a12)’) & 
& ’/home/kagr/Desktop/Data/uk/fields’/mapnr,’ukmap_c5.dat’

OPEN (1,FILE=prename,STATUS=’old’,ACTION=’read’)

READ (1,∗) dump,ncols
READ (1,∗) dump,nrows
READ (1,∗) dump,xllc
READ (1,∗) dump,ylle
READ (1,∗) dump,cellsize
READ (1,∗) dump,nodat_val

ysize=nrows
xsize=ncols
sizefac = cellsize /1000.

IF (allocated(hosts) .eqv. .false .) THEN
ALLOCATE(hosts(ysize,xsize,1+2*host_types))
hosts=0
ENDIF

DO n=1,nrows

READ (1,∗) hosts(n,:,1)

ENDDO

CLOSE (1)

!---- read in sheep

CALL random_number(x)
mapnr=NINT((tomapnr−frommapnr+1)*x−0.5)+frommapnr
mapnr=MIN(mapnr,tomapnr); mapnr=MAX(mapnr,frommapnr)

IF (area_sel==8) & 
& WRITE (prename,’(a34,i3.3,a11)’) &
& '/home/kagr/Desktop/Data/uk/fields/',mapnr,'ukmap.s.dat'

IF (area_sel==9) &
& WRITE (prename,'(a34,i3.3,a12)') &
& '/home/kagr/Desktop/Data/uk/fields/',mapnr,'ukmap.s2.dat'

IF (area_sel==10) &
& WRITE (prename,'(a34,i3.3,a12)') &
& '/home/kagr/Desktop/Data/uk/fields/',mapnr,'ukmap.s5.dat'

OPEN (1,FILE=prename,STATUS='old',ACTION='read')

READ (1,*) dump,ncols
READ (1,*) dump,nrows
READ (1,*) dump,xllc
READ (1,*) dump,yllc
READ (1,*) dump,cellsize
READ (1,*) dump,nodat_val

ysize=nrows
xsize=ncols

DO n=1,nrows

    READ (1,*) hosts(n,:,3)

ENDDO

END SELECT

!OPEN (17, file='chist3.dat', status='replace', action='write')
!OPEN (22, file='test.dat', status='replace', action='write')

IF (allocated(cpu) .eqv. . false . and. area_sel /=1) THEN
    ALLOCATE(cpu(ndata,3),chr2(ndata2))
    ALLOCATE(chr(ndata),cpu(ndata),upc(ndata),chk(ndata))
    ALLOCATE(pos2(ndata2,2),chk2(ndata2))
    ALLOCATE(area(ndata),graes(ndata),kvaeg(ndata),kvaeg2(ndata2))
    ALLOCATE(kpa(ndata),totarea(ndata))
    ALLOCATE(unikblok(ndata))
ENDIF

IF (allocated(csick_loc) .eqv. . false .) THEN
    ALLOCATE(csick_loc(a_hsick(1),h_var+hstages(1)+2))
ALLOCATE(msick_loc(a_msick,m_var+mstages+2))
ALLOCATE(csick_loc.com(a_hsick.c(1),4))
ENDIF
  csick_loc =0
  msick_loc=0
  csick_loc.com=0

IF (allocated(ssick_loc) .eqv. .false. .and. host_types>1) THEN
  ALLOCATE(ssick_loc(a_hsick(2),2+h_var+hstages(2)))
  ALLOCATE(ssick_loc.com(a_hsick.c(2),4))
ENDIF
  ssick_loc =0
  ssick_loc.com=0

IF (allocated(fly) .eqv. .false.) THEN
  ALLOCATE(fly(a_fly,3))
ENDIF

SELECT CASE (area_sel)
  CASE (1,5,8:13)
    RETURN
END SELECT

!---- READ FILES ----------------------------
READ (11,*) cdump
DO n=1,ndata
  READ (11,'(i6,x,a9,x,f12.3,x,f8.3,x,i4,x,i4)') &
  & chr(n),unikblok(n),area(n),graes(n),upc(n),cpun(n)
ENDDO

CLOSE (11)
!PRINT *,MAXVAL(cpun(:)),MAXLOC(cpun(:))
READ (2,*) cdump
DO n=1,ndata2
  READ (2,*) cdump,pos2(n,1),pos2(n,2),chr2(n),kvaeg2(n)
ENDDO

CLOSE (2)

!PRINT *,SUM(kvaeg2(:))

CALL seeed

!----- Randomly assign which farms have cattle on grass

i=1
kvaeg=0.
chk2=0
oldchr=0

DO n=1,ndata
  DO WHILE (chr(n)>=chr2(i))
    IF (chr(n)==chr2(i)) THEN
      IF (chr(n)!=oldchr) THEN
        CALL random_number(x)
        IF (x < ffw*hosts_outside(1)) THEN ! ffw = 1/farms with fields
          kvaeg(n)=kvaeg2(i)
          chk2(i)=1
        ELSE
          kvaeg(n)=0.
        ENDIF
      ELSE
        kvaeg(n)=kvaeg2(i)
      ENDIF
    ELSE
      kvaeg(n)=kvaeg2(i)
    ENDIF

    i=i+1
  ENDDO
  i=i-1
  oldchr=chr(n)
ENDDO

! print *,sum(chk2(:))
! stop

!——— Distribute cattle onto grass fields, prioritize fields with
!——— highest grass percentage, distribute with max 50 cows/ha.

cutoff=90.0000 !-- less than cutoff graes => no cows on this field
totarea=0.
kpa=0.
i=0
chk=0

DO n=1,ndata

   IF (i==0) THEN
      i=upc(n)
      j=upc(n)
      indlow=n-(upc(n)-i)
      indhi=n+i-1
      cutoff=90.0000
      totalarea=0.1
   ENDIF

   DO WHILE (kvaeg(n)/totalarea > 50./10000. .and. j>0)
      CALL random_number(x)
      field =NINT(x*(indhi-indlow-1))+indlow

      IF (graes(field) > cutoff .and. chk(field)==0) THEN
         totalarea=totalarea+area(field)/REAL(cpun(field))
         chk(field)=1
      ENDIF
      j=j-1
   ENDWHILE

   IF (j==0) THEN
      cutoff=cutoff-10.
      IF (cutoff > 1.) j=upc(n)
   ENDIF

ENDDO
ENDIF

IF (chk(n)==1) THEN

totarea(n)=totalarea
kpa(n)=kvaeg(n)/totalarea*10000.

ENDIF

i=i−1

! WRITE (3,'(i6,x,a9,x,f12.3,x,f8.3,x,i4,x,i4,x,f8.3,x,f15.3,x,f9.4)') &
!& chr(n),unikblok(n),area(n),graes(n),upc(n),cpun(n),kvaeg(n),totarea(n),&
!& kpa(n)

ENDDO

!------ data extraction
IF (2<1) THEN

hist=0

DO n=1ndata

IF (kpa(n)>0.001) hist(NINT(kpa(n)))=hist(NINT(kpa(n)))+1

ENDDO

DO n=0,432

WRITE (17,∗) n,hist(n)

ENDDO

PRINT *,maxval(kpa(:)),minval(kpa(:)),minval(totarea(:)),minloc(totarea(:))
!print *,sum(hist(:))
CLOSE (17)

ENDIF

!------ READ RASTER FILE -------------------------------

READ (1,*) dump,ncols
READ (1,*) dump,nrows
READ (1,*) dump,xllc
READ (1,*) dump, yllc
READ (1,*) dump, cellsize
READ (1,*) dump, nodat_val

! PRINT *, ncols, nrows, nodat_val, cellsize

ALLOCATE(map(ncols, nrows))
ALLOCATE(cpumap(ncols, nrows))
cpumap=0

DO i=1, nrows

    ! PRINT *, i

ENDDO

CLOSE (1)

DO n=1, ndata

    temp=unikblok(n)(1:6)/unikblok(n)(8:9)
    READ(temp,'(i8)') unikbloknr

    tmkpa=MAX(NINT(2.*kpa(n)),1)
    tkpa=binv(REAL((kpa(n)/REAL(tmkpa)), KIND(1.0D0)), tmkpa)

    cpu(n,:)=(/ chr(n) , unikbloknr , tkpa /) !==== NB ====

ENDDO

!---- Assign Cattle data ---------------

lcol=1; rcol=ncols
brow=1; trow=nrows
ysize=(rcol-lcol+1)
xsize=(trow-brow+1)

sizefac = cellsize /1000.

IF (allocated(cattle) .eqv. false.) THEN
ALLOCATE(cattle(ysize, xsize, 3))
ENDIF
IF (allocated(fly) .eqv. .false.) THEN
ALLOCATE(fly(a_fly,3))
ENDIF

IF (allocated(hosts) .eqv. .false.) THEN
ALLOCATE(hosts(ysize,xsize,1+2*host_types))
hosts=0
ENDIF

cattle=0
! midges=0

cpumap=0
cpumapp=0
! k=20
k=0
count=ndata2−SUM(chk2(:))

DO n=1,ndata2

IF (chk2(n)==0) THEN

IF (k>0 .and. count>1) THEN
   cpumapp=cpumapp+kvaeg2(n)
   k=k−1
   count=count−1
   CYCLE
ENDIF

cpumapp=cpumapp+kvaeg2(n)

j=FLOOR(REAL(pos2(n,1)−xllc)/cellsize)+1
i=FLOOR(REAL(pos2(n,2)−yllc)/cellsize)+1
cpumap(j,i)=cpumapp
! k=binv(REAL(0.5,KIND(1.0D0)),40)
k=0
count=count−1
cpumapp=0

ENDIF

ENDDO
DO i=brow,trow
  DO j=lcol,rcol

    cpumapp=0

    IF (map(j,i)==nodat_val) THEN

      DO n=1,ndata

        IF (map(j,i)==cpu(n,2)) THEN
          cpumap(j,i)=cpumap(j,i)+cpu(n,3)
          !cpumapp=cpu(n,3)
        IF (cpu(n)==1) EXIT
          !− NB use cpu better for faster program!
      ENDIF

      ENDDO

    ENDIF

    ENDDO

  ENDIF

  cattle(j,i,1)=cpumap(j,i)
  !midges(j,i,1)=mtc∗cpumap(j,i)
  !WRITE (22,'(i5,x)',advance='no') cpumap(j,i)

ENDDO

!WRITE (22,'(a)')
ENDDO

!close(22)

!print *,sum(cpumap(:,;))
hosts=0
hosts(:,1:2)= cattle(:,1:2)
!hosts(:,3:4)= cattle(:,1:2)/2
DEALLOCATE(cattle)

END SUBROUTINE read_mark_blocks

!============================================================

A.5.2 find_herds/find_farms (2.5.2)
SUBROUTINE find_herds
  USE gdata
  IMPLICIT NONE

  INTEGER :: n,cph(125118)

  IF (allocated(cphid) .eqv. .false .) CALL alloc_cphid

  cph=0

  DO ht=1,host_types
    DO n=1,hsick(ht)

      IF (ht==1) THEN
        cph(cphid(csick_loc(n,1), csick_loc(n,2)))=1
        IF (day==365) WRITE (44,* ) csick_loc(n,2),csick_loc(n,1),repeat
      ENDIF

      IF (ht==2) THEN
        cph(cphid(ssick_loc(n,1), ssick_loc(n,2)))=1
        IF (day==365) WRITE (44,* ) ssick_loc(n,2),ssick_loc(n,1),repeat
      ENDIF

    ENDDO
  ENDDO

  infcph=SUM(cph(:))

END SUBROUTINE find_herds

!=====================================================================

SUBROUTINE find_farms
  USE gdata
  IMPLICIT NONE

  INTEGER :: n,cph(125118),field

  IF (allocated(cphid) .eqv. .false .) CALL alloc_cphid

  cph=0

  DO ht=1,host_types
    DO n=1,hsick(ht)


IF (ht==1) THEN
  ! if (SUM(csick_loc(n,h_var+2:h_var+hstages(1)+1))>0) then
    field =cphid(csick_loc(n,1), csick_loc (n,2))
    cph(field)=1
  ! if (day==endday) write (44,* ) csick_loc(n,2), csick_loc (n,1), repeat
  IF (day==endday) WRITE (44,* ) field,repeat
  ! endif
ENDIF

IF (ht==2) THEN
  ! if (SUM(ssick_loc(n,h_var+2:h_var+hstages(2)+1))>0) then
    field =cphid(ssick_loc(n,1), ssick_loc (n,2))
    cph(field)=1
  ! if (day==endday) write (44,* ) ssick_loc(n,2), ssick_loc (n,1), repeat
  IF (day==endday) WRITE (44,* ) field,repeat
  ! endif
ENDIF
ENDDO
ENDDO

infcph=SUM(cph(:))

END SUBROUTINE find_farms

END MODULE
Appendix A

A.6 iomodule.f90 (2.6)

MODULE iomodule

CONTAINS

A.6.1 read_inputfile (2.6.1)

SUBROUTINE read_inputfile

USE gdata
USE iohosts
USE functions
IMPLICIT NONE

INTEGER :: n, check
CHARACTER :: dump*10, vdump*19

OPEN (41, FILE='input.txt', STATUS='old', ACTION='read')
check=1
!−−−−−− read header
DO n=1,22
    READ (41,*) dump
ENDDO

!−−−−−− read section A
READ (41,*, IOSTAT=ios, ERR=666) vdump, input_type
check=2
DO n=1,8
    READ (41,*) dump
ENDDO

!−−−−−− read section B
READ (41,*, IOSTAT=ios, ERR=666) vdump, area_sel
check=3
DO n=1,5
    READ (41,*) dump
ENDDO

IF (input_type==1 .and. area_sel==4) THEN
    READ (41,*, IOSTAT=ios, ERR=666) vdump, sizefac
    READ (41,*) dump
READ (41,*) dump
check=4
READ (41,*,IOSTAT=ios,ERR=666) vdump,xsize
!xsize=NINT(real(xsize)/sizefac)
READ (41,*,IOSTAT=ios,ERR=666) vdump,ysize
!ysize=NINT(real(ysize)/sizefac)
check=5
READ (41,*) dump
READ (41,*) dump
READ (41,*,IOSTAT=ios,ERR=666) vdump,n_farms(1)
READ (41,*,IOSTAT=ios,ERR=666) vdump,n_hosts(1)
READ (41,*) dump
READ (41,*) dump
READ (41,*,IOSTAT=ios,ERR=666) vdump,n_farms(2)
READ (41,*,IOSTAT=ios,ERR=666) vdump,n_hosts(2)
check=6
READ (41,*) dump
READ (41,*) dump
READ (41,*,IOSTAT=ios,ERR=666) vdump,nmean
nmean=MAX(nmean−1,0)
READ (41,*,IOSTAT=ios,ERR=666) vdump,nmax
IF (nmax<nmean) GOTO 666
check=7
ELSE
  DO n=1,17
    READ (41,*) dump
  ENDDO
ENDIF
DO n=1,7
  READ (41,*) dump
ENDDO

!—— read section C
READ (41,*,IOSTAT=ios,ERR=666) vdump,host_types
host_types=MIN(host_types,2)
!m_var=3+2*host_types
READ (41,*) dump
READ (41,*) dump

READ (41,*,IOSTAT=ios,ERR=666) vdump, hostsoutside(1)
hostsoutside = hostsoutside(1)/100.
READ (41,*) dump
READ (41,*) dump
check=8
READ (41,*,IOSTAT=ios,ERR=666) vdump, mstages
READ (41,*,IOSTAT=ios,ERR=666) vdump, hstages(1)
READ (41,*,IOSTAT=ios,ERR=666) vdump, hstages(2)
READ (41,*) dump
READ (41,*) dump
check=9
READ (41,*,IOSTAT=ios,ERR=666) vdump, hrec(1)
hrec(1) = 1./hrec(1)
READ (41,*,IOSTAT=ios,ERR=666) vdump, hrec(2)
hrec(2) = 1./hrec(2)
READ (41,*) dump
READ (41,*) dump
check=10
READ (41,*,IOSTAT=ios,ERR=666) vdump, wile
READ (41,*) dump
READ (41,*) dump
check=11
READ (41,*,IOSTAT=ios,ERR=666) vdump, probtrans_mh(1)
probtrans_mh = probtrans_mh(1)
READ (41,*) dump
READ (41,*) dump
check=12
READ (41,*,IOSTAT=ios,ERR=666) vdump, probtrans_hm(1)
probtrans_hm = probtrans_hm(1)
READ (41,*) dump
READ (41,*) dump
check=13
READ (41,*,IOSTAT=ios,ERR=666) vdump, flytime
READ (41,*) dump
READ (41,*) dump
check=14
READ (41,*,IOSTAT=ios,ERR=666) vdump, midgefly
READ (41,*) dump
READ (41,*) dump
check=15
READ (41,*,IOSTAT=ios,ERR=666) vdump, midgestay
READ (41,*) dump
READ (41,*) dump
check=16
READ (41,*,IOSTAT=ios,ERR=666) vdump, loclen
READ (41,*) dump
check=17
READ (41,*,IOSTAT=ios,ERR=666) vdump, mth
READ (41,*) dump
READ (41,*) dump
READ (41,*,IOSTAT=ios,ERR=666) vdump, vac_cov

!--- error message
666 IF (ios/=0) THEN
   WRITE (*,*) 'Read from Input.txt failed!', check
   STOP
ENDIF

!================================ Assignments ==============
loclen=loclen/sizefac/0.675
m_var=3+2*host_types

!================================ Assign values =========
SELECT CASE (input_type)
  CASE (1) ! Random distribution
    SELECT CASE (area_sel)
      CASE (1) ! Denmark
        sizefac =0.1
        xsize=4000
        ysize=3000
        n_farms(1)=17000
        n_farms(2)=0
        n_hosts(1)=1700000
        n_hosts(2)=0
        nmean=20
        nmax=48
        host_types=1
CASE (2) ! Lolland
  sizefac = 0.1
  xsize = 400
  ysize = 400
  n_farms(1) = 182
  n_farms(2) = 0
  n_hosts(1) = 8500
  n_hosts(2) = 0
  nmean = 15
  nmax = 48
  host_types = 1

CASE (3) ! Jutland
  sizefac = 0.1
  xsize = 400
  ysize = 400
  n_farms(1) = 1128
  n_farms(2) = 0
  n_hosts(1) = 117000
  n_hosts(2) = 0
  nmean = 25
  nmax = 48
  host_types = 1

CASE (4) ! Own def
  sizefac = sizefac

CASE (5) ! UK farms
  sizefac = 0.1
  xsize = 5182
  ysize = 4880
  n_farms(1) = 67020
  n_farms(2) = 58337
  n_hosts(1) = 6247964
  n_hosts(2) = 21929519
  nmean = 0
  nmax = 48
  host_types = 2

CASE DEFAULT
WRITE (*,*) 'Selected input type for B1 (when A1=1) must be 1,2,3,4 or 5!
STOP

END SELECT
ht=1; CALL distribute
IF (host_types==2) THEN
  ht=2; CALL distribute
ENDIF

CASE (2) ! CHR−Data

SELECT CASE (area_sel)
  CASE (1:3,5,8:13)
    CALL read_mark_blocks
    loclen=loclen/sizefac/0.675
  CASE DEFAULT
    WRITE (*,*) 'Selected input type for B1 (when A1=2) must be 1:3,5,8:13'
    STOP
END SELECT

CASE DEFAULT
WRITE (*,*) 'Selected input type in A1 must be 1 or 2'
STOP
END SELECT

END SUBROUTINE

END MODULE
#### INPUT FILE for BTV-SPREAD program ####

# Author: Kaare Græsbøll (Graesboell) contact: kagr@imm.dtu.dk
#

Instructions:

---

A. SECTION:

A1: Choose Random distribution (1) or CHR/CPH-Data (2):

Value.A1............: 2

---

B. SECTION

B1: Choose region: Denmark (1), Lolland (2), Jutland (3), own definition (4), UK farms (5), UK pasture sc 1,2,5 (8,9,10), DK-b sc 2,3,5 (11,12,13)

Value.B1............: 12

---

If A1=1 and B1=4 Define:

side length of each grid cell (km): REAL
...sizefac............: 0.1

Size of area (grids): INTEGER
...xsize............: 5182
...ysize............: 4880
...number of cattle: INTEGER !uk 67020
...farms+fields....: 67020
...cattle..........: 6247964
...number of sheep: INTEGER !uk 58337, 19040196
...farms+fields....: 58337
...sheep...........: 21929519

Field distribution defined by binomial distribution: INTEGER
...mean.size.(np)...: 1
...max.size.(n)...: 48
---

C: SECTION

host types: (1) cattle (2) cattle + sheep: INTEGER (must be 2!)
...hosts_types.....: 2

percentage of hosts outdoors: INTEGER
...hosts_out.......: 0

stages of infection to mimic Gamma-dist for: INTEGER
...midges..........: 40
...cattle..........: 5
...sheep..........: 7        !--- different because of dt

Recovery time for host (days): REAL
...cattle..........: 20.6
...sheep..........: 16.4

width to length scale in wind spread cone: REAL
...width.to.length...: 0.5

probability of transmission midge -> host: REAL
probtrans_mh......: 0.9

probability of transmission host -> midge: REAL
probtrans_hm......: 0.1

length of midge flight time (hours): REAL
flytime............: 1.5

. 
fraction of midges that fly with the wind: REAL
midgefly..........: 0.05

. 
fraction of midges that stay where no hosts: REAL
midgestay........: 0.05

. 
local length scale for M random walk (km 50% of midges reach): REAL
loclen............: 0.5

. 
number of midges per host (vectors per host): INTEGER
mth...............: 5000

. 
vaccination cover (fraction): REAL
vac_cov...........: 0.
A.7 host.f90 (2.7)

MODULE host ! moves hosts

CONTAINS

A.7.1 host_move (2.7.1)

SUBROUTINE host_move !— sub to move hosts

USE gdata
USE functions
IMPLICIT NONE

INTEGER :: nmove,h,tomove,htomove,m,l,i,j,k,tot
host,hid
REAL :: x(3), dist,angle,y

DO ht=1,host_types

nmove=binv(REAL(hmove(ht),KIND(1.0D0)),NINT(1.∗hsick(ht)/hmovef(ht)))

DO h=1,nmove

!— which host to move — only sick gets to be moved
CALL random_number(x(:))
tomove=ceiling(x(1)∗hsick(ht))

IF (ht==1 .and. SUM(csick_loc(tomove,(h.var+2):(h.var+hstages(ht)+1)))==0) & & CYCLE
IF (ht==2 .and. SUM(ssick_loc(tomove,(h.var+2):(h.var+hstages(ht)+1)))==0) & & CYCLE

IF (ht==1) THEN
i=csick_loc(tomove,1)
j=csick_loc(tomove,2)
ENDIF

IF (ht==2) THEN
i=ssick_loc(tomove,1)
j=ssick_loc(tomove,2)
ENDIF

!— deleted part from v964 check host move dist
`!− where to move based on 'decription of inputs dk FMD'

\[
dist = (12. \ast (-\log((1.000001 - x(2))/1.2)) \ast \ast 2.)/\text{sizefac}
\]

\[
dist = \text{MIN}(dist, 300./\text{sizefac})
\]

\[
\text{angle} = 2. \ast \pi \ast x(3)
\]

\[
\text{IF} (\text{movingrestrictions}) \quad \text{dist} = \text{MIN}(\text{dist}, 50./\text{sizefac})
\]

\[
m = i + \text{NINT}(\text{dist} \ast \sin(\text{angle}))
\]

\[
l = j + \text{NINT}(\text{dist} \ast \cos(\text{angle}))
\]

\[
m = \text{MAX}(m, 1); m = \text{MIN}(m, \text{ysize})
\]

\[
l = \text{MAX}(l, 1); l = \text{MIN}(l, \text{xsize})
\]

\[
'\text{write (27,*) dist, angle, m, i, l, j}
\]

\[
k = 1
\]

\[
i = m; j = l
\]

kloop: \textbf{DO WHILE} (hosts(m, l, (2 * ht - 1)) == 0)

\[
!−− if needed introduce randomness by modulo statement
\]

\[
m = \text{MIN}(i + k, \text{ysize})
\]

\[
\text{DO} \ 1 = \text{MAX}(j - k, 1), \text{MIN}(j + k, \text{xsize})
\]

\[
\text{IF} (\text{hosts}(m, l, (2 * \text{ht} - 1))/=0) \text{ EXIT kloop}
\]

\textbf{ENDDO}

\[
m = \text{MAX}(i - k, 1)
\]

\[
\text{DO} \ l = \text{MAX}(j - k, 1), \text{MIN}(j + k, \text{xsize})
\]

\[
\text{IF} (\text{hosts}(m, l, (2 * \text{ht} - 1))/=0) \text{ EXIT kloop}
\]

\textbf{ENDDO}

\[
l = \text{MIN}(j + k, \text{xsize})
\]

\[
\text{DO} \ m = \text{MAX}(i - k, 1), \text{MIN}(i + k, \text{ysize})
\]

\[
\text{IF} (\text{hosts}(m, l, (2 * \text{ht} - 1))/=0) \text{ EXIT kloop}
\]

\textbf{ENDDO}

\[
l = \text{MAX}(j - k, 1)
\]

\[
\text{DO} \ m = \text{MAX}(i - k, 1), \text{MIN}(i + k, \text{ysize})
\]

\[
\text{IF} (\text{hosts}(m, l, (2 * \text{ht} - 1))/=0) \text{ EXIT kloop}
\]

\textbf{ENDDO}

\[
k = k + 1
\]
ENDDO kloop

!- register the move
i=m; j=l
tot_host=hosts(i,j,1)
IF (host_types>1) tot_host=tot_host+hosts(i,j,3)

IF (hosts(i,j,2*ht)==0) THEN
hsick(ht)=hsick(ht)+1

IF (hsick(ht)>=a_hsick(ht)) CALL re_al_hsick

IF (ht==1) THEN
csick_loc (ht,:) = 0
csick_loc (ht,1:(h_var+1)) = &
& (/i,j,hosts(i,j,1+2*host_types),tot_host,&
& hosts(i,j,ht) /

IF (hosts(i,j,1+2*host_types)/=0) &
& msick_loc(hosts(i,j,1+2*host_types),3)=hsick(ht)
ENDIF

IF (ht==2) THEN
ssick_loc (ht,:) = 0
ssick_loc (ht,1:(h_var+1)) = &
& (/i,j,hosts(i,j,1+2*host_types),tot_host,&
& hosts(i,j,ht+1) /)

IF (hosts(i,j,1+2*host_types)/=0) &
& msick_loc(hosts(i,j,1+2*host_types),5)=hsick(ht)
ENDIF

hid=hsick(ht)

hosts(i,j,2*ht)=hid
ELSE
hid = hosts(i,j,2*ht)
ENDIF

IF (ht==1) THEN
DO k=(h_var+2),(h_var+hstages(ht)+1)
htomove=binv(REAL(hmovef(ht),KIND(1.0D0)),csick_loc(tomove,k))
csick_loc (tomove,k)=csick_loc(tomove,k)+htomove
csick_loc (tomove,h_var+1)=csick_loc(tomove,h_var+1)+htomove
csick_loc(hid,k) = csick_loc(hid,k) + htomove
csick_loc(hid,h_var+1) = csick_loc(hid,h_var+1) − htomove

ENDDO

!write (28,*), csick_loc(hsick(ht,:),’...’, hosts(i,j,:))
ENDF

IF (ht==2) THEN
DO k=(h_var+2),(h_var+hstages(ht)+1)
htomove=binv(REAL(hmovef(ht), KIND(1.0D0)), ssick_loc(tomove,k))
ssick_loc(tomove,k) = ssick_loc(tomove,k) − htomove
ssick_loc(tomove,h_var+1) = ssick_loc(tomove,h_var+1) + htomove
ssick_loc(hid,k) = ssick_loc(hid,k) + htomove
ssick_loc(hid,h_var+1) = ssick_loc(hid,h_var+1) − htomove
ENDDO

!write (28,*), ssick_loc(hsick(ht,:),’...’, hosts(i,j,:))
ENDIF

ENDDO
ENDDO

END SUBROUTINE host_move

END MODULE
MODULE temperatures !contains code related to temperature

CONTAINS

A.8.1 temp_var_h (2.8.1)

SUBROUTINE temp_var_h !--- determine parameters based on hourly temperature
                !--- watch it if the mean temperatures goes above 27C

USE gdata
IMPLICIT NONE
REAL(mk) :: T,m_clim,T_clim,ntmin(max_id_temp),ntmax(max_id_temp)
REAL(mk) :: dt,ndt,th(24),heip(24),hbite(24),toff
INTEGER :: mit,dump,n

!toff = 2.

IF (day==1) THEN
  DO n=1,max_id_temp
    READ (21,'(i4,x,i5,2(x,f5.1),2(x,f5 .2), x,f7 .2) ') dump,dump,tmin(n),tmax(n)
    tmin(:)=tmin(:)+toff
    tmax(:)=tmax(:)+toff
  ENDDO
ENDIF

IF (day==365) REWIND (21)

DO n=1,max_id_temp
  READ (21,'(i4,x,i5,2(x,f5.1),2(x,f5 .2), x,f7 .2) ') dump,dump,ntmin(n),ntmax(n)
  ntmin(n)=ntmin(n)+toff
  ntmax(n)=ntmax(n)+toff
  dt = tmax(n)-tmin(n)
  ndt = tmax(n)-ntmin(n)
  T=(tmax(n)+tmin(n))/2.
  th(:)= (/ tmin(n), 0.017*dt+tmin(n), 0.067*dt+tmin(n), 0.146*dt+tmin(n), &
               0.250*dt+tmin(n), 0.371*dt+tmin(n), 0.500*dt+tmin(n), &
               0.629*dt+tmin(n), 0.750*dt+tmin(n), 0.854*dt+tmin(n), &
               0.957*dt+tmin(n), 1.000*dt+tmin(n) /)
& 0.933*dt+tmin(n), 0.983*dt+tmin(n), tmax(n), &
& 0.983*ndt+ntmin(n), 0.933*ndt+ntmin(n), 0.854*ndt+ntmin(n), &
& 0.750*ndt+ntmin(n), 0.629*ndt+ntmin(n), 0.500*ndt+ntmin(n), &
& 0.371*ndt+ntmin(n), 0.250*ndt+ntmin(n), 0.146*ndt+ntmin(n), &
& 0.067*ndt+ntmin(n), 0.017*ndt+ntmin(n)/)

!heip(:) = 0.0000125*th(:)*(th(:)−10.4) !— old EIP
heip(:) = 0.018*(th(:)−13.4)/24.

!mrec(n) = MAX( SUM(heip, mask = th .gt. 10.4) , 0.01 ) !— old EIP
mrec(n) = MAX( SUM(heip, mask = th .gt. 13.4) , 0.01 )

mmort(n) = MAX(1.−exp(−0.009.mk*exp(0.16.mk*T)) , 0.1)

hbite(:)=(0.0002*th(:)*(th(:)−3.7)*(41.9−th(:))**((0.37))/24.
biterate (n) = SUM(hbite, mask = th .gt. 3.7)

mboxes(n) = MAX( NINT(0.5/mrec(n)) , 3 )
mboxes(n) = MIN( NINT(0.5/mrec(n)) , 11 )
mbjr(n) = (1.*mstages)/(1.*mboxes(n))
mbji(n) = NINT(mbjr(n))

IF (.FALSE.) THEN !— add microclimate temperatures to eip

T_clim=T+2.5
m_clim = MAX(0.01,0.0003.mk*T_clim*(T_clim−10.4.mk))
IF (T_clim<0.) m_clim = 0.01

mboxes(n) = MAX( NINT(1./m_clim)−1 , 1 )
mbjr(n) = (1.*mstages)/(1.*mboxes(n))
mbji(n) = NINT(mbjr(n))

ENDIF

ENDDO

temperature=T
tmin=ntmin
tmax=ntmax

!— Seasonal midges ——

IF (day>150 .and. day<310) THEN
mth=NINT(abs(sin(pi*(day−150.)/42.)*2950.*sin(pi*(day−150.)/160.)))+50
ELSE
   mth=0
ENDIF
! mth=700

END SUBROUTINE temp_var_h

!====================================================================

A.8.2 read_temp_id (2.8.2)

SUBROUTINE read_temp_id
USE gdata
IMPLICIT NONE

INTEGER :: icols,irows,n,mit

SELECT CASE (area_sel)

   CASE (1)
      OPEN (57,FILE=’/home/kagr/Desktop/Data/temperature/temp_indexr.dat’, &
           & STATUS=’old’,ACTION=’read’)  
      max_id_temp=70

   CASE (4,5,8)
      OPEN (57,FILE=’/home/kagr/Desktop/Data/uk/temp_indexr_uk.dat’, &
           & STATUS=’old’,ACTION=’read’) 
      max_id_temp=19

   CASE (9)
      OPEN (57,FILE=’/home/kagr/Desktop/Data/uk/temp_indexr_uk2.dat’, &
           & STATUS=’old’,ACTION=’read’) 
      max_id_temp=19

   CASE (10)
      OPEN (57,FILE=’/home/kagr/Desktop/Data/uk/temp_indexr_uk5.dat’, &
           & STATUS=’old’,ACTION=’read’) 
      max_id_temp=19

   CASE (11)
      OPEN (57,FILE=’/home/kagr/Desktop/Data/temperature/temp_indexr2.dat’, &
           & STATUS=’old’,ACTION=’read’) 
      max_id_temp=70
CASE (12)
OPEN (57, FILE='"/home/kagr/Desktop/Data/temperature/temp_indexr3.dat", 
&
& STATUS='old', ACTION='read')
max_id_temp=70

CASE (13)
OPEN (57, FILE='"/home/kagr/Desktop/Data/temperature/temp_indexr5.dat", 
&
& STATUS='old', ACTION='read')
max_id_temp=70

CASE DEFAULT
PRINT *, 'No temperature index map available for the selected area'
STOP

END SELECT

icols=xsize
irows=ysize

ALLOCATE(id_temp(irows,icols))

DO n=1,icols

READ (57,*) id_temp(:,n)

ENDDO

mit=max_id_temp

CLOSE (57)

ALLOCATE(mrec(mit), mmort(mit), biterate(mit), mboxes(mit), mbjr(mit), mbji(mit))
ALLOCATE(tmin(mit), tmax(mit))

END SUBROUTINE read_temp_id

END MODULE
A.9 makemap.f90 (2.9)

MODULE makemap ! Distributes cattle from raster files

CONTAINS

A.9.1 make_mark_blocks (2.9.1)

SUBROUTINE make_mark_blocks
USE gdata
USE functions
IMPLICIT NONE

INTEGER :: ndata, ndata2
INTEGER :: n, i
INTEGER :: idump, j, indhi, indlow, field
INTEGER :: cpumapp, oldchr, count, m
INTEGER :: ncols, nrows, nodat, val, k, unikbloknr
INTEGER :: trow, brow, lcol, rcol, location, tkpa, tmkpa

INTEGER, ALLOCATABLE :: map(:,), cpumap(:,), cpu(:,), chr2(:)
INTEGER, ALLOCATABLE :: chr(:,), cpun(:,), upc(:,), chk(:,), blokno(:,)
INTEGER, ALLOCATABLE :: pos2(:,), chk2(:,), blok(:,), cblok(:,)

REAL :: xllc, yllc, cellsize, rdump, dist, distc, ccpu, fwf
REAL :: totalarea, cattdens, x, cutoff

REAL, ALLOCATABLE :: area(:,), graes(:,), kvaeg(:,), kvaeg2(:,)
REAL, ALLOCATABLE :: kpa(:,), totarea(:,)

CHARACTER :: dump*14, temp*8, cdump*99
CHARACTER, ALLOCATABLE :: unikblok(:,)*9

SELECT CASE (area_sel)

!---- Denmark without bornholm

!---- shared chr permitted!

CASE (1)
   OPEN (1,FILE='/home/kagr/Desktop/Data/fields/ubr_dk-b1.dat',&
          STATUS='old', ACTION='read')
OPEN (11, FILE = '/home/kagr/Desktop/Data/fields/check_dk−b1.dat', &
 &   STATUS = 'old', ACTION = 'read')
OPEN (2, FILE = '/home/kagr/Desktop/Data/fields/kvaegdata_dk−b1.dat', &
 &   STATUS = 'old', ACTION = 'read')
ndata = 100631; ndata2 = 21877 ! rescale = 1
fwf = 1./(16472./21877.) !− fwf resc 1

CASE (11)
  OPEN (1, FILE = '/home/kagr/Desktop/Data/fields/ubr_dk−b2.dat', &
 &   STATUS = 'old', ACTION = 'read')
  OPEN (11, FILE = '/home/kagr/Desktop/Data/fields/check_dk−b2.dat', &
 &   STATUS = 'old', ACTION = 'read')
  OPEN (2, FILE = '/home/kagr/Desktop/Data/fields/kvaegdata_dk−b2.dat', &
 &   STATUS = 'old', ACTION = 'read')
ndata = 89756; ndata2 = 21877 ! rescale = 2
fwf = 1./(16364./21877.) !− fwf resc 2

CASE (12)
  OPEN (1, FILE = '/home/kagr/Desktop/Data/fields/ubr_dk−b3.dat', &
 &   STATUS = 'old', ACTION = 'read')
  OPEN (11, FILE = '/home/kagr/Desktop/Data/fields/check_dk−b3.dat', &
 &   STATUS = 'old', ACTION = 'read')
  OPEN (2, FILE = '/home/kagr/Desktop/Data/fields/kvaegdata_dk−b3.dat', &
 &   STATUS = 'old', ACTION = 'read')
ndata = 81492; ndata2 = 21877 ! rescale = 3
fwf = 1./(16281./21877.) !− fwf resc 3

CASE (13)
  OPEN (1, FILE = '/home/kagr/Desktop/Data/fields/ubr_dk−b5t.dat', &
 &   STATUS = 'old', ACTION = 'read')
  OPEN (11, FILE = '/home/kagr/Desktop/Data/fields/check_dk−b5t.dat', &
 &   STATUS = 'old', ACTION = 'read')
  OPEN (2, FILE = '/home/kagr/Desktop/Data/fields/kvaegdata_dk−b5t.dat', &
 &   STATUS = 'old', ACTION = 'read')
ndata = 64444; ndata2 = 21877 ! rescale = 5
ndata = 48043; ndata2 = 21877 ! rescale = 5t
fwf = 1./(11780./21877.) !− fwf resc 5
fwf=1./(14790./21877.) !— fwp resc 5t

CASE DEFAULT
  PRINT *,’ERROR IN CHOSING AREA_SEL!!!’
  STOP

END SELECT

IF (allocated(cpu) .eqv. . false .) THEN
  ALLOCATE(cpu(ndata,3),chr2(ndata2))
  ALLOCATE(chr(ndata),cpu(n,ndata),chk(ndata))
  ALLOCATE(pos2(ndata2,2),chk2(ndata2),blokno(ndata))
  ALLOCATE(area(ndata),graes(ndata),kvaeg(ndata),kvaeg2(ndata2))
  ALLOCATE(kpa(ndata),totarea(n,ndata),blokid(93577,13),cblokid(93577))
  ALLOCATE(unikblok(n,ndata))
ENDIF

IF (allocated( csick_loc ) .eqv. . false .) THEN
  ALLOCATE(csick_loc(a_hsick(1),h_var+hstages(1)+2))
  ALLOCATE(msick_loc(a_msick,m_var+mstages+2))
  ALLOCATE(csick_loc_com(a_hsick_c(1),4))
ENDIF
  csick_loc=0
  msick_loc=0
  csick_loc_com=0

IF (allocated( ssick_loc ) .eqv. . false . .and. host_types>1) THEN
  ALLOCATE(ssick_loc(a_hsick(2),2+h_var+hstages(2))))
  ALLOCATE(ssick_loc_com(a_hsick_c(2),4))
ENDIF
  ssick_loc=0
  ssick_loc_com=0

IF (allocated( fly ) .eqv. . false .) THEN
  ALLOCATE(fly(a_fly,3))
ENDIF

!—— READ FILES ————————————

READ (11,*) cdump

blokid=0; cblokid=0
count=0
DO n=1,ndata

!READ (11, '(i6,x,i5,x,f12.1,x,f8.3,x,i4,x,i4)')
READ (11, '(i6,x,i5,x,f12.3,x,f8.3,x,i4,x,i4)') &
   & chr(n),blokno(n),area(n),graes(n),upc(n),cpun(n)

IF (blokno(n)==0) CYCLE

cblokid(blokno(n))=cblokid(blokno(n))+1
blok(id(blokno(n),cblokid(blokno(n))))=n

ENDDO

CLOSE (11)

!PRINT *, MAXVAL(blokno(:)), MAXVAL(cpun(:)), count

!stop

READ (2,*) cdump

DO n=1,ndata2

   READ (2,*) cdump,pos2(n,1),pos2(n,2),chr2(n),kvaeg2(n)

ENDDO

CLOSE (2)

!PRINT *, SUM(kvaeg2(:))

!--- READ RASTER FILE ---------------------

READ (1,*) dump,ncols
READ (1,*) dump,nrows
READ (1,*) dump,xllc
READ (1,*) dump,ylbc
READ (1,*) dump,cellsiz
READ (1,*) dump,nodat_val

!PRINT *, ncols, nrows, nodat_val, cellsiz

ALLOCATE(map(ncols,nrows))
ALLOCATE(cpumap(ncols,nrows))
cpumap=0
IF (allocated(hosts) .eqv. . false .) THEN
ALLOCATE(hosts(ysize,xsize,1+2*host_types))
ENDIF
hosts=0
DO i=1,nrows

    READ (1,*) map(:,i)
    !PRINT *,i
ENDDO
CLOSE (1)
DO n=1,ndata
    unikbloknr=blokno(n)
    tmkpa=MAX(NINT(2.*kpa(n)),1)
    tkpa=binv(REAL((kpa(n)/REAL(tmkpa)),KIND(1.0D0)),tmkpa)
    cpu(n,:)=(/ chr(n) , unikbloknr , tkpa /) !==== NB ==== ENDDO

!---- READ some from RASTER FILE -----------------------
READ (1,*) dump,ncols
READ (1,*) dump,nrows
READ (1,*) dump,xllc
READ (1,*) dump,yllc
READ (1,*) dump,cellsize
READ (1,*) dump,nodat_val
REWIND (1)

!--------------------------
CALL seeed

!---- Randomly assign which farms have cattle on grass
i=1
kvaeg=0.
chk2=0
oldchr=0

DO n=1,ndata

   DO WHILE (chr(n)>=chr2(i))

      IF (chr(n)==chr2(i)) THEN

         IF (chr(n)!=oldchr) THEN
            CALL random_number(x)
            IF (x < fwf*hosts_outside(1)) THEN ! fwf = 1/farms with fields
               kvaeg(n)=kvaeg2(i)
               chk2(i)=1
            ELSE
               kvaeg(n)=0.
            ENDIF
         ELSE
            kvaeg(n)=kvaeg2(i)
         ENDIF
      ENDIF

      ELSE
         kvaeg(n)=kvaeg2(i)
      ENDIF

      i=i+1

   ENDDO

   i=i-1

   oldchr=chr(n)

ENDDO

! print *,sum(chk2(:))
!stop

!------ Distribute cattle onto grass fields, prioritize fields with
!------ highest grass percentage, distribute with max 50 cows/ha.

cutoff=90.0000 ! less than cutoff graes => no cows on this field
totarea=0.
kpa=0.
i=0
chk=0

DO n=1,ndata

IF (i==0) THEN
  i=upc(n)
  j=upc(n)
  indlow=n-(upc(n)-i)
  indhi=n+i-1
  cutoff=90.0000
  totalarea=0.1

  !do while (kvaeg(n)/totalarea > 50./10000. .and. j>0)
  DO WHILE (kvaeg(n)/totalarea > 50./(cellsize**2.) .and. j>0)

    CALL random_number(x)
    field =NINT(x*(indhi-indlow))+indlow

    IF (graes(field) > cutoff .and. chk(field)==0) THEN
      totalarea=totalarea+area(field)/REAL(cpun(field))
      chk(field)=1
    ENDIF

    j=j-1

    IF (j==0) THEN
      cutoff=cutoff-10.
      IF (cutoff > 1.) j=upc(n)
    ENDIF
  ENDDO

ENDIF

IF (chk(n)==1) THEN
  totarea(n)=totalarea
  kpa(n)=kvaeg(n)/totalarea*cellsize**2.
ENDIF

i=i-1
! WRITE (3,'(i6,x,a9,x,f12.3,x,f8.3,x,i4,x,i4,x,f8.3,x,f15.3,x,f9.4)') &
! & chr(n),unikblok(n),area(n),graes(n),upc(n),cpun(n),kvaeg(n),totarea(n),&
! & kpa(n)
ENDDO
!

−−− Assign Cattle data −−−−−−−−−−−−−−

lcol =1; rcol=ncols
brow=1; trow=nrows

ysize=(rcol−lcol+1)
xsize=(trow−brow+1)

sizefac = cellsize /1000.

cpumap=0
cpumapp=0
!k=20
k=0
count=ndata2−SUM(chk2(:))

DO n=1,ndata2

IF (chk2(n)==0) THEN
   IF (k>0 .and. count>1) THEN
      cpumapp=cpumapp+kvaeg2(n)
k=k−1
      count=count−1
   CYCLE
   ENDIF

   cpumapp=cpumapp+kvaeg2(n)
   
   j=FLOOR(REAL(pos2(n,1)−xllc)/cellsize)+1
   i=FLOOR(REAL(pos2(n,2)−yllc)/cellsize)+1
   cpumap(j,i)=cpumapp
   !k=binv(REAL(0.5,KIND(1.0D0)),40)
k=0
   count=count−1
cpumapp=0

ENDIF

ENDDO

DO i=brow,trow
  DO j=lcol,rcol
    cpumapp=0
    IF (map(j,i)/=nodat.val) THEN
      n=cblokid(map(j,i))
      IF (n/=0) THEN
        DO m=1,n
          field =blokid(map(j,i),m)
          cpumap(j,i)=cpumap(j,i)+cpu(field,3)/REAL(cpun(field))
        ENDDO
      ENDIF
    ENDIF

    ! cattle (j , i,1)=cpumap(j,i)
    !WRITE (22,'(i5,x)',advance='no') cpumap(j,i)
  ENDDO

ENDDDO

END SUBROUTINE

hosts(:,1)= cpumap(:,)

END SUBROUTINE

END MODULE makemap
A.10 viraemia.f90 (2.10)

MODULE viraemia
!----- This module handles how cattle and midges move through infection stages.

CONTAINS

A.10.1 host_viraemia (2.10.1)

SUBROUTINE host_viraemia

USE gdata
USE functions

IMPLICIT NONE
INTEGER :: i,j,k,h,dc

ht=1
DO h=1,hsick(ht)
    IF (SUM(csick_loc(h,h_var+2:h_var+hstages(ht)+1))==0) CYCLE
    DO k=h_var+hstages(ht)+1,h_var+2,-1
        IF (csick_loc(h,k)==0) CYCLE
        dc=binv(REAL((hrec(ht)*hstages(ht)),KIND(1.0D0)),csick_loc(h,k))
        csick_loc(h,k)=csick_loc(h,k)−dc
        csick_loc(h,k+1)=csick_loc(h,k+1)+dc
    ENDDO
    !write (28,* day,h,SUM(csick_loc(h,5:10)), csick_loc(h,1:2) ! testing.dat
ENDDO

IF (host_types>1) THEN
    ht=2
    DO h=1,hsick(ht)
        IF (SUM(ssick_loc(h,h_var+2:h_var+hstages(ht)+1))==0) CYCLE
    ENDDO
DO k=h_var+hstages(ht)+1,h_var+2,-1
   IF ( ssick_loc (h,k)==0) CYCLE
   dc=binv(REAL((hrec(ht)*hstages(ht)),KIND(1.0D0)),ssick_loc(h,k))
   ssick_loc (h,k)=ssick_loc(h,k)−dc
   ssick_loc (h,k+1)=ssick_loc(h,k+1)+dc
ENDDO
ENDDO
ENDIF
END SUBROUTINE host_viraemia

!=====================================================================

A.10.2 midge_viraemia (2.10.2)

SUBROUTINE midge_viraemia

USE gdata
USE functions

IMPLICIT NONE
INTEGER :: i,j,k,h,dm,ddm,jump,jt,T_id,cand,smbji,smboxes,T_ido,m
REAL :: x,jc,y(2),smbjr,smrec,smmort

T_ido=0

DO h=1,msick
   IF (SUM(msick_loc(h,m_var+2:))==0) THEN
      hosts(msick_loc(h,1),msick_loc(h,2),1+2*host_types)=0
      IF (msick_loc(h,3) /=0) csick_loc (msick_loc(h,3),3)=0
      IF (host_types>1 .and. msick_loc(h,5) /=0) ssick_loc (msick_loc(h,5),3)=0
      msick_loc(h,:)=0
      CYCLE
   ENDIF
T_id=id_temp(msick_loc(h,1),msick_loc(h,2)) !—maybe faster if T_id in msick

IF (T_id/=T_ido) THEN
   smbjr=mbjr(T_id)
   smbji=mbji(T_id)
   smrec=mrec(T_id)
   smmort=mmort(T_id)
   smboxes=mboxes(T_id)
   T_ido=T_id
ENDIF

IF (msick_loc(h,mstages+m_var+2)>0) THEN
   ddm=binv(REAL(smmort,KIND(1.0D0)),msick_loc(h,mstages+m_var+2))
   msick_loc(h,mstages+m_var+2)=msick_loc(h,mstages+m_var+2)−ddm
   !msick_loc(h,m_var+1)=msick_loc(h,m_var+1)+ddm
   !—maintains constant amount of midges
ENDIF

jc=0.
CALL random_number(x)
IF (x<abs(smbjr−1.*smbji)) jc=1.
jc=sign(jc,smbjr−1.*smbji)
jump=smbji+jc

DO k = (mstages+m_var+1) , (m_var+2) ,−1
   cand=msick_loc(h,k)
   SELECT CASE (cand)
      CASE (0)
         CYCLE
      CASE (1:5)
         dm=0; ddm=0
         DO m=1,cand
            CALL random_number(y)
            IF (y(1)<smmort) THEN
               ddm=ddm+1
         ELSE IF (y(2)<smrec*smboxes) THEN
            dm=dm+1
         ENDIF
     ENDIF
   ENDSELECT
ENDDO

dm = MIN(dm, cand - ddm)

CASE DEFAULT

  ddm = binv(REAL(smmort, KIND(1.0D0)), cand)
  dm = binv(REAL(smrrec*smboxes, KIND(1.0D0)), cand - ddm)

END SELECT

jt = min(k + jump, m_var + mstages + 2)

msick_loc(h, k) = cand - dm - ddm
msick_loc(h, jt) = msick_loc(h, jt) + dm
! msick_loc(h, m_var + 1) = msick_loc(h, m_var + 1) + ddm
! -- maintains constant amount of midges

ENDDO

IF (SUM(msick_loc(h, m_var + 2:)) == 0) THEN
  hosts(msick_loc(h, 1), msick_loc(h, 2), 1 + 2*host_types) = 0
  IF (msick_loc(h, 3) /= 0) csick_loc(msick_loc(h, 3), 3) = 0
  IF (host_types > 1 .and. msick_loc(h, 5) /= 0) ssick_loc(msick_loc(h, 5), 3) = 0
  msick_loc(h,:) = 0
ENDIF

ENDDO

END SUBROUTINE

END MODULE
A.11 windy.f90 (2.11)

MODULE windy

CONTAINS

A.11.1 wind_data (2.11.1)

SUBROUTINE wind_data
USE gdata
IMPLICIT NONE
REAL(mk) :: x,y

CALL random_number(x); CALL random_number(y)
! x = 0.5 mk; y = 0.5 mk

wind_a = 2. mk pi*x
! wind_a = 2. * pi*x + 0.5 * sin(2.*pi*x + 3.*pi/4.) - 0.3536 ! wind uk
! wind_a = 2. * pi*x + 0.75 * sin(2.*pi*x + 3.*pi/4.) - 0.53
wind_s = 5. mk*y

END SUBROUTINE

END MODULE
A.12  midge.f90 (2.12)

MODULE midge
!--- Notice: to save calc.time healthy midges do not fly!

CONTAINS

A.12.1  midge_local (2.12.1)

SUBROUTINE midge_local
USE gdata
USE functions
IMPLICIT NONE
INTEGER :: i,k,j,l,m,h,BM
USE call,midgesflying,hh,midgesfly
REAL(mk) :: x(2),y,theta, Rnorm,length,local_midgefly

! fly = 0
BM_call=0
fly_c =0
ht=host_types

DO h=1,msick

  IF (SUM(msick_loc(h,m_var+2:))==0) THEN
    !msick_loc(h,(m_var+1):)=0
    CYCLE
  ENDIF

  i=msick_loc(h,1)
  j=msick_loc(h,2)

  IF (msick_loc(h,3+2*host_types) == 0) THEN
    local_midgefly=MAX(1._mk−midgestay,0._mk)
  ELSE
    local_midgefly=midgefly
  ENDIF

  DO k=m_var+2,m_var+mstages+2

    IF (msick_loc(h,k)==0) CYCLE

    midgesflying=binv(REAL(local_midgefly,KIND(1.0D0)),msick_loc(h,k))
    midgesfly=0
DO hh=1,midgesflying

!—find fly coordinates in cylindrical coord. u. BOX–MULLER

IF (BM_call==0) THEN
CALL RANDOM_NUMBER(x)
theta = 2.mk * pi * x(1)
Rnorm = sqrt(-2.mk * log(x(2)+10.*2(16.)))

length = ABS( Rnorm*sin(theta) ) * loclen
BM_call=1
ELSE
length = ABS( Rnorm*cos(theta) ) * loclen
BM_call=0
ENDIF

CALL RANDOM_NUMBER(y)
y= 2.mk * pi * y

m=NINT( length* sin( y ) ) + i
l=NINT( length* cos( y ) ) + j

!——— midges only fly to the edge of the simulation box
!m=MIN(m,ysize); m=MAX(1,m)
!l=MIN(l,xsize); l=MAX(1,l)

IF (m/=i .or. l/=j) THEN
IF (m>=1 .and. m<=ysize .and. l>=1 .and. l<=xsize) THEN
IF (day<flyminit) THEN
   fly_c=fly_c+1
   IF (fly_c>=a_fly) CALL re_al_fly
   fly ( fly_c :)=(/ m,l,k /)
ELSE
   flym(m,l,k-(m_var+1))=flym(m,l,k-(m_var+1))+1
ENDIF
midgesfly=midgesfly+1!———don’t fly
ENDIF
!midgesfly=midgesfly+1!——disappear over the edge
ENDIF

ENDDO
msick_loc(h,k)=msick_loc(h,k)−midgesfly

ENDDO

! if ((SUM(midges(i,j,2:))−SUM(fly_local(i,j,:)))==0) write (29,*) &
!& SUM(midges(i,j,2:mstages+2)),SUM(fly_local(i,j,:)),h,msick

ENDDO

END SUBROUTINE midge_local

!=========================================

A.12.2  midge_wind (2.12.2)

SUBROUTINE midge_wind
USE gdata
USE functions
USE windy
IMPLICIT NONE
INTEGER :: i,k,j,l,m,h,midgesflying,hh,count,midgesfly
REAL(mk) :: x(2),angle,length,lesc,theta,Rnorm,wisc,windcut,wind_midgefly,y

fly =0
fly_c =0

!− 0.90 midges is carried within 45 deg.
wisc=(pi/4._mk) / 1.645_mk

! if 0.90 midges fly within 1 square −> then cycle
windcut=(sizefac*1.645)/(flytime*3.6_mk)

CALL wind_data !−− All msick_loc should be updated in here.

DO h=1,msick

IF (SUM(msick_loc(h,(m_var+2):))==0) THEN
  CYCLE
ENDIF

IF (wind_s<windcut) CYCLE

!− 0.90 midges is carried within lescc
lesc=flytime*3.6_mk*wind_s/sizefac/1.645_mk
i=msick_loc(h,1)
j=msick_loc(h,2)

IF (msick_loc(h,3+2*host_types) == 0) THEN
  wind_midgefly=MAX(1._mk−midgestay,0._mk)
ELSE
  wind_midgefly=midgefly/5.
ENDIF

DO k= (m_var+2), mstages+m_var+2
  IF (msick_loc(h,k)==0) CYCLE
  midgesflying=binv(REAL(wind_midgefly,KIND(1.0D0)),msick_loc(h,k))
  midgesfly=0
  DO hh=1,midgesflying
    !−find fly coordinates in cylindrical coord. BOX−MULLER

    CALL RANDOM_NUMBER(x)
    theta = 2._mk * pi * x(1)
    Rnorm = sqrt(−2._mk * log(x(2)+10.**(-16.)))
    !log−term might cause Arithmetic error

    angle = Rnorm*sin(theta) * wisc + wind_a
    length = ABS( Rnorm*cos(theta) ) * lesc

    m=NINT( length* sin( angle ) ) + i
    l=NINT( length* cos( angle ) ) + j

    !−−−−−−−− midges only fly to the edge of the simulation box
    !m=MIN(m,ysize); m=MAX(1,m)
    !l=MIN(l,xsize); l=MAX(1,l)

    IF (m/=i .or. l/=j) THEN
      IF (m>=1 .and. m<=ysize .and. l>=1 .and. l<=xsize) THEN
        IF (day<flyminit) THEN
          fly_c=fly_c+1
          IF (fly_c>=a_fly) CALL re_al_fly
          fly ( fly_c ,:)=(/ m,l,k /)
        ELSE
          flym(m,l,k−(m_var+1))=flym(m,l,k−(m_var+1))+1
      ENDIF
    ENDIF
  ENDIF
ENDDO
ENDIF
midgesfly = midgesfly + 1 !-- or don’t fly
ENDIF
! midgesfly = midgesfly + 1 !-- disappear over the edge
ENDIF

ENDDO

msick_loc(h,k) = msick_loc(h,k) − midgesfly

ENDDO

! if ((SUM(midges(i,j,2:)) − SUM(fly_wind(i,j,:))) == 0) write (29,*) &
! & SUM(midges(i,j,2:)),SUM(fly_wind(i,j,:))

ENDDO

END SUBROUTINE midge_wind

END MODULE
A.13  bite.f90 (2.13)

MODULE bite

CONTAINS

A.13.1  inf_hosts (2.13.1)

SUBROUTINE inf_hosts

USE gdata
USE functions

IMPLICIT NONE
INTEGER :: i,j,k,hid,h,susc,tot_host,T_id,vac_d
REAL(mk) :: vac

DO h=1,msick

    IF (msick_loc(h,mstages+2+m_var)==0) CYCLE

    i=msick_loc(h,1)
    j=msick_loc(h,2)

    DO ht=1,host_types

        IF (msick_loc(h,2+2*ht)==0) CYCLE

        IF (msick_loc(h,1+2*ht)>0) THEN
            IF (ht==1) susc=csick_loc(msick_loc(h,3),h_var+1)
            IF (ht==2) susc=ssick_loc(msick_loc(h,5),h_var+1)
        ELSE
            susc=msick_loc(h,2+2*ht)
        ENDIF

        tot_host=msick_loc(h,3+2*host_types)
        T_id=id_temp(i,j)
        !T_id=1

        ! if (vac_cov>0.1) then
        !vac_d=vac_id(cphid(i,j))
        !vac=(1.−real(day−vac_d)/tfp(ht)*efficacy)
        ! if (day>=(vac_d+tfp(ht))) vac=(1.-efficacy)
! if (day<vac_d) vac=1.
! endif
vac=1.-vac_cov*efficacy

k=binv(REAL(biterate(T_id)*probrans_mh(ht)*vac* &
& msick_loc(h,mstages+2+m_var)/(1.*tot_host),KIND(1.0D0)),susc)

IF (k>0) THEN
IF (msick_loc(h,1+2*ht)==0) THEN
hsick(ht)=hsick(ht)+1

IF (hsick(ht)>=a_hsick(ht)) CALL re_al_hsick

IF (ht==1) THEN
csick_loc (hsick(ht),1:(h_var+1)) = &
& (/i,j,h,tot_host,hosts(i,j,ht) /

ENDIF

IF (ht==2) THEN
ssick_loc (hsick(ht),1:(h_var+1)) = &
& (/i,j,h,tot_host,hosts(i,j,ht+1) /

ENDIF

hid=hsick(ht)

msick_loc(h,1+2*ht) = hid
hosts(i,j,2*ht)=hid
ELSE
hid = msick_loc(h,1+2*ht)
ENDIF

IF (ht==1) THEN
csick_loc (hid,h_var+1)=csick_loc(hid,h_var+1)+k
csick_loc (hid,h_var+2)=csick_loc(hid,h_var+2)+k
ENDIF

IF (ht==2) THEN
ssick_loc (hid,h_var+1)=ssick_loc(hid,h_var+1)+k
ssick_loc (hid,h_var+2)=ssick_loc(hid,h_var+2)+k
ENDIF

!write (27,*) day,ht,k, tot_host , msick_loc(h,mstages+2+m_var),i,j
ENDIF
ENDDO
ENDDO

END SUBROUTINE inf_hosts

!==================================================

A.13.2 inf_midges (2.13.2)

SUBROUTINE inf_midges

USE gdata
USE functions

IMPLICIT NONE
INTEGER :: i,j,h,tot,mid,T
REAL (MK) :: inf,h,vac,x

!=== CATTLE ===
ht=1
DO h=1,hsick(ht)
  i=csick_loc(h,1)
  j=csick_loc(h,2)
  tot_h=SUM(csick_loc(h,(h_var+1):))

  IF (SUM(csick_loc(h,(h_var+2):(h_var+hstages(ht)+1)))==0) CYCLE

  inf_h=REAL(SUM(csick_loc(h,h_var+2:h_var+hstages(ht)+1)),MK)
  inf_h=0.50*MK*csick_loc(h,h_var+2)+&
  & 2.00*MK*csick_loc(h,h_var+3)+&
  & 2.00*MK*csick_loc(h,h_var+4)+&
  & 0.50*MK*csick_loc(h,h_var+5)

  T_id=id_temp(i,j)

  ! if (vac_cov>0.1) then
  !vac_d=vac_id(cphid(i,j))
  ! vac=(1.-real(day-vac_d)/tfp(ht)*efficacy)
  ! if (day>=(vac_d+tfp(ht))) vac=(1.-efficacy)
  ! if (day<vac_d) vac=1.
  ! endif
vac = 1.0 - vac_cov*efficacy

mid = csick_loc(h,3)

! --- assign vector to host ratio ---
IF (varmth) THEN
  IF (mid == 0) THEN
    CALL random_number(x)
    lmth = NINT(x*mth)
  ELSE
    lmth = msick_loc(mid,m_var+1)
    IF (lmth == 0) THEN
      CALL random_number(x)
      lmth = NINT(x*mth)
    ENDIF
    msick_loc(mid,m_var+1) = lmth
  ENDIF
ENDIF
ELSE
  lmth = mth
ENDIF

IF (varmthdk) THEN
  CALL random_number(x)
  lmth = NINT(x*mth)
ENDIF

! ---

k = binv(REAL(biterate(T_id)*probrans_hm(ht)*vac_inf_h,KIND(1.0D0)),lmth)

IF (k > 0 .and. mid == 0) THEN
  msick = msick + 1
  IF (msick >= a_msick) CALL re_al_msick
  msick_loc(msick,:) = 0
  msick_loc(msick,1:4) = (/i,j,h,tot_h/)
  msick_loc(msick,3+2*host_types) = hosts(i,j,1)
  IF (host_types > 1) msick_loc(msick,3+2*host_types) = &
     & msick_loc(msick,3+2*host_types) + hosts(i,j,3)
  msick_loc(msick,m_var+1) = lmth
  mid = msick
  csick_loc(h,3) = mid ! err count!
  hosts(i,j,1+2*host_types) = mid
ENDIF

!write (28,*) ht,k,inf_h,biterate(T_id),temperature
msick_loc(mid,m_var+2)=msick_loc(mid,m_var+2)+k
!msick_loc(mid,m_var+1)=msick_loc(mid,m_var+1)−k

ENDDO

IF (host_types>1) THEN

!=== SHEEP ===
ht=2
DO h=1,hsick(ht)

i=ssick_loc(h,1)
j=ssick_loc(h,2)
tot_h=SUM(ssick_loc(h,(h_var+1):))

IF (SUM(ssick_loc(h,(h_var+2):(h_var+hstages(ht)+1)))==0) CYCLE

IF (oo_transkernel) THEN

hsick_com(ht)=hsick_com(ht)+1
IF (hsick_com(ht)>=a_hsick_c(ht)) CALL real_hsick_com

ssick_loc_com(hsick_com(ht),:)=(/i,j,day,h/)

ENDIF

!/inf_h=REAL(SUM(ssick_loc(h,h_var+2:h_var+hstages(ht)+1)),mk)
inf_h= 0.50*mk*SUM(ssick_loc(h,h_var+2 :h_var+3 ) )+&
& 2.00*mk*SUM(ssick_loc(h,h_var+4 :h_var+6))+&
& 0.50*mk*SUM(ssick_loc(h,h_var+7:h_var+8))

T_id=id_temp(i,j)

!/ if (vac_cov>0.1) then
!vac_d=vac_id(cphid(i,j))
!vac=(1.−real(day−vac_d)/tfp(ht)*efficacy)
!/ if (day>=(vac_d+tfp(ht))) vac=(1.−efficacy)
!/ if (day<vac_d) vac=1.
!endif

vac=1.−vac_cov*efficacy

mid=ssick_loc(h,3)

!/ --- assign vector to host ratio ---
IF (varmth) THEN

IF (mid==0) THEN
CALL random_number(x)
lnth=NINT(x*mth)
ELSE
lnth=msick_loc(mid,m_var+1)
IF (lnth==0) THEN
CALL random_number(x)
lnth=NINT(x*mth)
msick_loc(mid,m_var+1)=lnth
ENDIF
ENDIF
ELSE
lnth=mth
ENDIF

IF (varmthdk) THEN
CALL random_number(x)
lnth=NINT(x*mth)
ENDIF

!−−−

k=binv(REAL(biterate(T_id)*protrans_hm(ht)*vac*inf_h,KIND(1.0D0)),lnth)

IF (k>0 .and. mid==0) THEN
msick=msick+1
IF (msick>=a_msick) CALL re_al_msick
msick_loc(msick,1:2)=(/i,j/)
msick_loc(msick,5:6)=(/h,tot_h/)
msick_loc(msick,3+2*host_types)=hosts(i,j,1)+hosts(i,j,3)
msick_loc(msick,m_var+1)=lnth
mid=msick
ssick_loc (h,3)=mid !err count!
hosts(i,j,1+2*host_types)=mid
ENDIF

msick_loc(mid,m_var+2)=msick_loc(mid,m_var+2)+k
!msick_loc(mid,m_var+1)=msick_loc(mid,m_var+1)−k
ENDDO
ENDIF

END SUBROUTINE inf_midges
END MODULE
A.14  errorhandl.f90 (2.14)

MODULE errorhandl

CONTAINS

A.14.1  findmidges (2.14.1)

SUBROUTINE findmidges  ! test if midge ID is correctly handled in the hosts

USE gdata

IMPLICIT NONE

INTEGER :: i,j,k,mlist(msick)

IF (msick==0) RETURN

! if (2<1) then
mlist=0
DO i=1,ysize
  DO j=1,xsize
    IF (hosts(i,j,1+2*host_types)>0) THEN
      mlist(hosts(i,j,1+2*host_types))=mlist(hosts(i,j,1+2*host_types))+1
      IF (i/=msick_loc(hosts(i,j,1+2*host_types),1)) THEN
        WRITE (27,*) day,i,j,msick_loc(hosts(i,j,1+2*host_types),1:2),
        & hosts(i,j,1+2*host_types),msick
        errorcounter=errorcounter+1
      ENDIF
    ENDIF
  ENDDO
ENDDO

! endif
!

ENDDO
ENDDO

!endif

! if (2<1) then
DO k=1,msick
  IF (k/=hosts(msick_loc(k,1),msick_loc(k,2),1+2*host_types)) THEN


WRITE (28,*) day,k,hosts(msick_loc(k,1),msick_loc(k,2),1+2*host_types)
errorcounter=errorcounter+1
ENDIF

IF (mlist(k)>1) THEN
WRITE (28,*) day,k,mlist(k)
errorcounter=errorcounter+1
ENDIF

ENDDO
! endif
flush (27)
flush (28)

END SUBROUTINE

!==============================================

A.14.2 findhosts (2.14.2)

SUBROUTINE findhosts !—−− check if hosts have been correctly registered
USE gdata
IMPLICIT NONE
INTEGER :: n,i,j,k
DO n=1,msick
i=msick_loc(n,1)
j=msick_loc(n,2)
IF (i==0 .or. j==0) CYCLE

IF (msick_loc(n,m_var)== (hosts(i,j,1)+hosts(i,j,3))) THEN
WRITE (27,*) n,i,j,msick_loc(n,m_var),hosts(i,j,1),hosts(i,j,3)
errorcounter=errorcounter+1
ENDIF

IF (msick_loc(n,3)>0) THEN
IF (n/=csick_loc(msick_loc(n,3),3)) THEN
WRITE (27,*) '1',n,csick_loc(msick_loc(n,3),3),&
& hosts(i, j,1+2*host_types),msick_loc(n,3), hsick(1), &
& i, j, csick_loc (msick_loc(n,3),1:2)
errorcounter=errorcounter+1
ENDIF
ENDIF

IF (host_types>1 .and. msick_loc(n,5)>0) THEN
  IF (n/=ssick_loc(msick_loc(n,5),3)) THEN
    WRITE (27,* ) '2',n,ssick_loc(msick_loc(n,5),3), &
& hosts(i, j,1+2*host_types),msick_loc(n,5), hsick(2), &
& i, j, ssick_loc (msick_loc(n,5),1:2)
errorcounter=errorcounter+1
  ENDIF
ENDIF
ENDIF

ENDDO

DO n=1,hsick(1)

  i=csick_loc(n,1)
  j=csick_loc(n,2)
  IF (i==0 .or. j==0) CYCLE

  IF ( csick_loc (n,4)/= (hosts(i, j,1)+hosts(i, j,3))) THEN
    WRITE (27,* ) n,i,j,csick_loc(n,4),hosts(i, j,1), hosts(i, j,3)
errorcounter=errorcounter+1
  ENDIF

ENDIF

IF (SUM(csick_loc(n,5))/= hosts(i, j,1)) THEN
  WRITE (27,* ) n,i,j,csick_loc(n,5),hosts(i, j,1)
errorcounter=errorcounter+1
ENDIF

IF ( csick_loc (n,3)>0) THEN
  IF (i/=msick_loc(csick_loc(n,3),1)) THEN
    WRITE (27,* ) &
& '1',n,i,msick_loc( csick_loc (n,3),1)
errorcounter=errorcounter+1
  ENDIF
ENDIF

ENDDO

DO n=1,hsick(2)
i = sick_loc(n,1)
j = sick_loc(n,2)
IF (i == 0 .or. j == 0) CYCLE

IF (sick_loc(n,4) /= (hosts(i, j,1) + hosts(i, j,3))) THEN
WRITE (28,*) n, i, j, sick_loc(n,4), hosts(i, j,1), hosts(i, j,3)
errorcounter = errorcounter + 1
ENDIF

IF (SUM(sick_loc(n,5:)) /= hosts(i, j,3)) THEN
WRITE (28,*) n, i, j, sick_loc(n,5), hosts(i, j,3)
errorcounter = errorcounter + 1
ENDIF

IF (sick_loc(n,3) > 0) THEN
IF (i /= msick_loc(sick_loc(n,3),1)) THEN
WRITE (28,*) & '2', n, i, msick_loc(sick_loc(n,3),1)
errorcounter = errorcounter + 1
ENDIF
ENDIF
ENDDO

IF (.true.) THEN
DO n = 1, hsick(1)
 i = csick_loc(n,1)
j = csick_loc(n,2)

DO k = 1, hsick(2)

IF (i == sick_loc(k,1) .and. j == sick_loc(k,2) .and. &
 & csick_loc(n,3) /= sick_loc(k,3)) THEN
WRITE (28,*) day, n, k, csick_loc(n,1:3), sick_loc(k,1:3)
errorcounter = errorcounter + 1
ENDIF
ENDDO
ENDDO
ENDIF

flush (27); flush (28)

END SUBROUTINE

END MODULE
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