Disease Model Cradle (DMC) practical

Introduction

The "Disease Model Cradle" (or DMC) is an application which provides an interactive front-end to run a variety of disease models (including LMM and the Rift Valley Fever model when available). Disease models encapsulated as dynamic libraries are plugged into the application using a standardised interface, and the run results displayed graphically. The aim of this multi-platform tool is to allow end-users to run models in their local institutions with their own meteorological datasets and to investigate and validate the results with respect to epidemiological field measurements (e.g. malaria incidences, number of infected mosquitoes for the LMM).

DMC is available for different platforms (Windows, Mac OS X, etc). In this practical we will mainly focus on using the Liverpool Malaria Model (LMM) within DMC on the Windows platform.

The LMM (Hoshen and Morse, 2004) is a dynamic malaria model consisting of two coupled climate-driven components, a disease transmission model and a mosquito population model. The transmission of the parasite between human and mosquito hosts incorporates temperature-dependency in both the rate of development of the parasite within the mosquito (the sporogonic cycle) and the mosquito biting rate (the gonotrophic cycle). The mosquito population model incorporates both temperature and rainfall-dependency, with the availability of mosquito breeding sites and larval mosquito mortality rate both dependent on decadal (10 day) accumulations of rainfall, and the adult mosquito survival probability dependent on temperature (a number of published survival schemes are available via DMC). A 2011 study (Ermert et al., 2011a, 2011b) extended the original model as developed by Hoshen and Morse and carried out detailed calibration and validation of the extended model to derive a recommended parameter set for West Africa. Both the original and 2010 parameter settings of the LMM can be obtained via DMC. LMM has been used for both seasonal epidemic forecasting (Jones and Morse, 2010) and climate change (Ermert et al. 2011c) applications. See Appendix A for recommended parameter settings, definitions of the model output variables and diagrams of the model structure.

Please note that the LMM is a model, so results might be different from reality!

Installation

Windows version: Run the executable file called "DMC_vX.Y.exe" (where X & Y are version numbers, e.g. DMC_v1.0.exe). Double-click on the file and click 'Next' until the installation is successful. All program files are stored under the default windows directory "C:\Program Files\DMC" if this is not modified during the installation. Click on the 'Start' button (bottom left of screen) and run the DMC entry. Tip: If you had a previous version of DMC installed on your system, after the new installation uninstall using the program "C:\Program Files\DMC\unins000.exe" and then redo the installation to resolve conflicts in registry entries created by the old (beta) version.

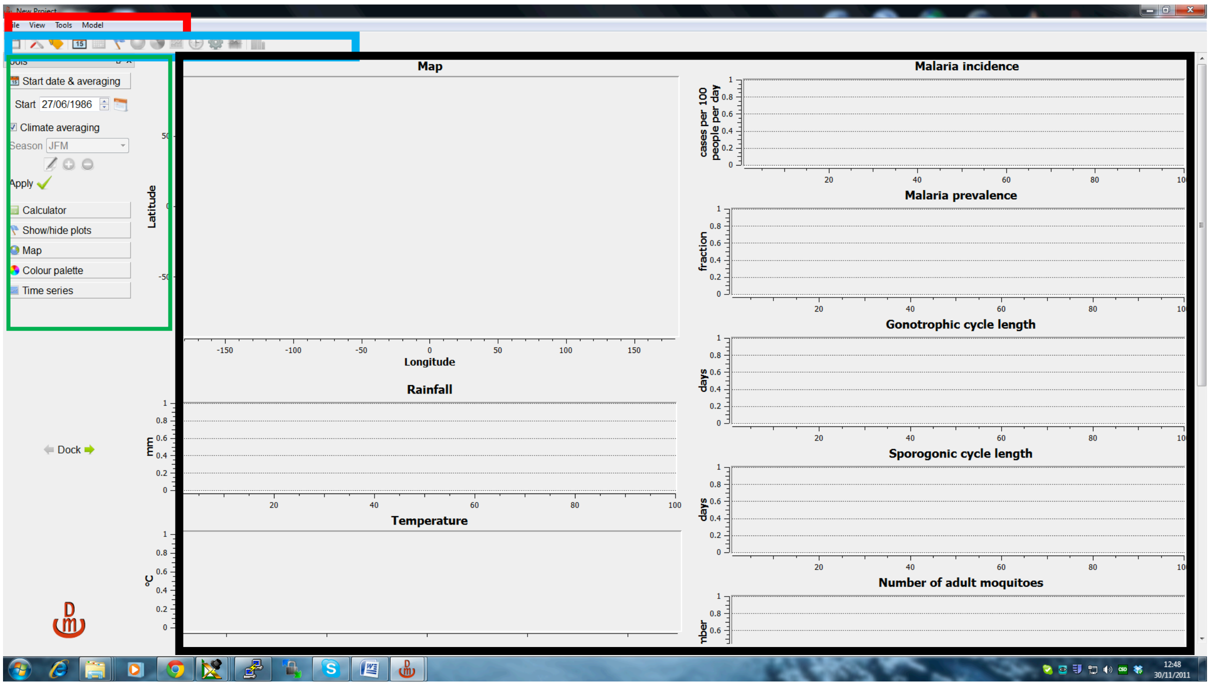
Mac OS X version: Mount the disk image file "DMC_vX.Y.dmg" (where X & Y are version numbers, e.g. DMC_v1.0.dmg). Double-click on the image to show the contents in a folder and follow the instructions in the "INSTALL.txt" file.

The data for this practical is in the folder “Senegal_example”. Copy this folder onto your system (e.g. the desktop). Please note the location of the folder – we will call the location <*your_location*> in this practical. So the example files will be located in the folder “<*your_location*>\Senegal_example” (using Windows notation).

First steps with DMC

To begin select the DMC entry in the Start menu (Windows) or in the Applications folder (Mac OS X). Or double-click on “C:\Program Files\DMC\DMC.exe” for the Windows version.

The DMC graphical interface looks like this:



Like all software there are different ways to access the different functionalities of DMC:

The menu bar (red box): File, View, Tools, Models, on the top

The tool icon bar (blue box): Save, Averaging, Animation, etc icons just below the menu bar

The tool box (green box): Start date and averaging, Calculator… on the left hand side, can be pinned on the right hand side by clicking on Dock control (green ‘right’ arrow), or can be detached (closed) from the main window by using the double-window icon (cross icon) on the top right corner of the tool box. If you lose the toolbox you can just click on the screw driver icon in the tool icon bar to make it reappear.

The graphical board (black box): where all inputs and outputs of the model used within DMC are displayed (map and charts). The former example shows empty plots for the typical inputs and outputs of the Liverpool Malaria Model (LMM).

To start you can just move and hover your mouse pointer for few seconds over the different icons in the icon bar and elements of the toolbox. The functionalities are briefly detailed as a text tip. Note that DMC also supports a French translation of the user interface (we will detail this point later) if you’re not familiar with English.

Import input data:

For the LMM, the required input datasets are daily rainfall (in mm) **and** daily temperature (in °C).

In the menu bar, click on File->Import->Rainfall

A dialog box appears, then open the rainfall text file called "rain_Senegal.txt" in the folder "*<your_location>*\Senegal_example".

In the menu bar, Click on File->Import->Temperature

Again, a dialog box appears, then open the temperature text file called "temp_Senegal.txt" from the same folder "*<your_location>*\Senegal_example".

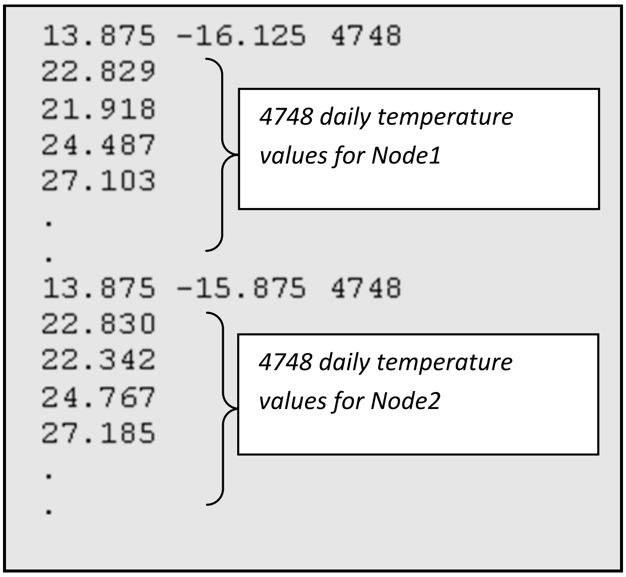
On the left hand side of the graphical board, the inputs should be shown as a gridded contour map and two histograms.

Input data format:

Open the file "temp_Senegal.txt" with a text editor (e.g. *Notepad* or *TextEdit*).

The input dataset must be in ASCII (text format) and must be ordered like:

Latitude1 (°) Longitude1 (°) ntime (days)
Value day 1 (i.e. value for 1st Jan 1998)
Value day 2 (i.e. value for 2nd Jan 1998)
.
.
.
.
.
Value day Ntime (i.e. value for 31st Dec 2010)
Latitude1 (°) Longitude2 (°) ntime (days)
Value day 1 (i.e. value for 1st Jan 1998)
Value day 2 (i.e. value for 2nd Jan 1998)
.
.
.
.
.



For this example we have used ERAINTERIM temperature gridded data and TRMM rainfall gridded data at 0.25°x0.25° resolution covering the period 1998-2010 (4748 days) over a domain covering Senegal (lat = 10.5°N-17°N, lon = -18°E - -11°E or 18°W-11°W). The longitude convention is based on a centered Greenwich System (from 180°W to 180°E, negative for western longitudes).

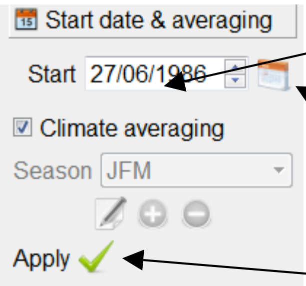
Using this format you can import **gridded** or **station** datasets. We define a 'node' as a geographical point (e.g. a grid node or a station position). All data can be in one single file (like the former example, where all nodes are concatenated in the same text file) or in separate files (one file per node, keeping the spatial latitude / longitude reference and the number of time steps on the first line of each file, which is easier for station dataset). If you have one file per node, you can import multiple files simultaneously into DMC by selecting all the files in the Import File box. All nodes should have the same common reference time period and no missing data values are allowed.

DMC project and functionalities: Start date

Scale the time period* 15 *shortcut CTRL+SHIFT+D

NOTE: DMC DOES NOT AUTOMATICALLY KNOW THE START TIME OF YOUR IMPORTED DATA.

The first thing to do is to enter the start time of your dataset. For this Click on the **start date and averaging** icon (in the toolbox or the tool icon bar or the menu Tools->Start Date and averaging)



*In the Start box, you can **manually** modify the start date or*

*Use the **Choose date calendar icon** on the right of this box.*

*Click on **Apply** changes*

For this example set the start date to 01/01/1998 (which is the start date of the rainfall and temperature dataset for Senegal). Do not forget to apply you changes by clicking on the Apply changes

The histograms should now show realistic rainfall and temperature seasonal profiles for Senegal. The rainy season occurs between June and November and the warmest season in March-April-May. Note that the current version of DMC only works for the standard Gregorian/Julian calendar (365 days with leap years).

DMC project and functionalities: Open, save a project and preferences

Save DMC file: shortcut CTRL+SHIFT+S

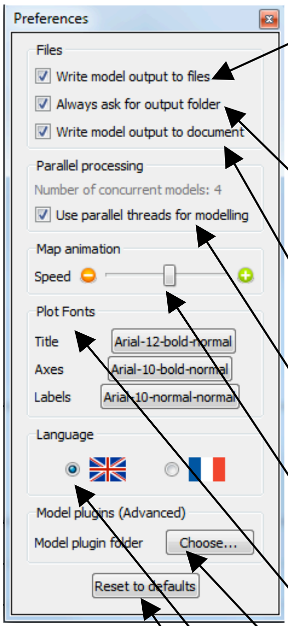
In the menu file: File->Save (or File->Save As). A dialog box will open, you can now save your project as a *.dmc file. Name it "Senegal_example1" and save it to your desktop. You can also use the Save button in the icon bar to save your project. Then quit DMC.

Open DMC file: shortcut CTRL+O

Restart DMC and in the menu: File->Open then select the file you just saved on your Desktop "Senegal_example1.dmc" (or just simply double-click on the file as you would do for a Word document). All modifications you made above have been taken into account; you can now continue to work on your DMC project document.

Preferences:

In the menu bar click File->Preferences, the Preferences dialog box will appear with the default settings:



Write Model output to files*: Allow saving the daily model outputs (here the LMM, so outputs such as "Daily malaria incidence"…) in text files to allow the user to do further analysis on the output data (more details later in the section about running the LMM with DMC). Enabled by default.*

Always ask for output folder*: The DMC software will ask you for the directory where you want to store the model outputs every time the model is run.*

Write Model output to document*: Check this box if you want to save the model output (in this example from the LMM) to your *.dmc project file.*

Use parallel threads for modeling*: Activate parallel processing, this is enabled by default (modeling is faster if your computer has multiple cores).*

Map animation speed*: define the speed of the animation (see later on in the practical)*

Plot fonts*: Allow changing the font of the title, axes and labels on the plots.*

Model Plugin folder*: Define the location of the disease models you can select within DMC. Do not modify if you're not an advanced user.*

Language*: Choose English or French as the user interface language.*

You can restore all modifications to the Preferences by pressing the "Reset to Defaults" button.

Initially uncheck the box "Write model output to files" as we do not want to save any model outputs at the moment.

DMC project and functionalities: Play and interact with the graphics

The DMC graphics are all interactive!

To start you can click on the rainfall histogram on the bar for the month of August. The map changes to show rainfall patterns for the month of August as well. Do the same on the temperature histogram on the bar for the month of March, the map now shows mean temperatures for the month of March.

The map is also interactive. First click on the rainfall histogram bar to display rainfall on the map. Then click on a node in the map: the time series (histograms) shown below the map are now those corresponding to this specific node. A cross appears in the node that is selected on the map and the corresponding lat/lon coordinates are written in the title of the displayed histograms.

Example: Click on the rainfall map on the lower left corner node (10.5°N, -18°E). You can see that the rainfall season ranges from June to November with relatively large rainfall amounts. Do the same on the top left corner node (10.5°N, -18°E): the histogram changes and depicts a shorter rainy season lasting from July to October (Sahelian profile).

Note that both input (rainfall and temperature in the LMM example) and output (e.g. malaria incidence, number of infectious mosquitoes…) plots are interactive. Actually we are focusing on the model climatic inputs - we will talk later about the model outputs.

Apply mask to the map:

In the Menu Bar: Tools->Apply mask or in the icon bar click on the mask icon. This will popup a dialog box to open the mask text file you want to apply to your data. Open the file “mask_Senegal.txt” which is located in “*<your_location>*\Senegal_example”. All nodes that do not belong to Senegal have now been masked. The mask file format is an ASCII text file and the format is consistent with other input file format:

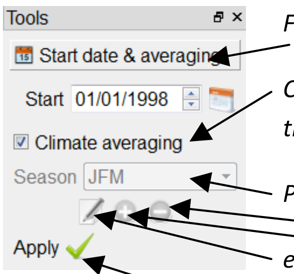
Latitude1 (°) Longitude1 (°) 1
One mask Value (0 hidden, 1 shown)
Latitude1 (°) Longitude2 (°) 1
Mask Value (0 hidden, 1 shown)
.
.
.
Latitude_i (°) Longitude_j (°) 1
Mask Value (0 hidden, 1 shown)

```
10.625 -17.875 1
0
10.625 -17.625 1
0
10.625 -17.375 1
0
10.625 -17.125 1
0
```

You can open the file “mask_Senegal.txt” with a text editor (Notepad, TextEdit, etc) to inspect the format. You do not have to define an entry for every possible node in the mask file: you can just add specific entries with a ‘0’ to hide certain nodes. Nodes that are not defined within the mask file are assumed to be visible.

Time manipulation: shortcut CTRL+SHIFT+D

In the tool box click on the “Start date and averaging” button, or in the tool box click on the calendar icon or in the menu bar: Tools->Start Date and averaging.



For the start date see previously

Climate averaging: the data shown are based on a mean seasonal cycle averaged for the whole time period. Uncheck the box if you want to display seasonal means.

Pickup a predefined season (need to uncheck Climate averaging to activate) or

edit, create or delete a season

and then apply changes

N.B. We already fixed the start date of the climatic data we are using to 01/01/1998.

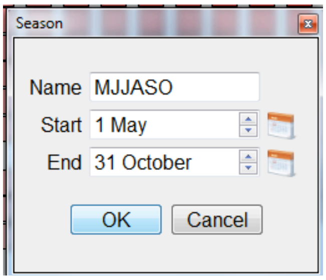
We are now going to play with the different time functionalities. By default the data are displayed for “climate averaging”. This means that the mean seasonal cycle of the input and output data is computed for the whole time period (1998-2010 in this example).

You can uncheck the box “climate averaging” and select a standard season that might interest you. JFM stands for January-February-March seasonal average, FMA for February-March-April seasonal average, etc.

Select JAS (July-August-September) by choosing from the season pulldown menu. Click on Apply. Now all graphics depict annual values for this typical season. Click on a node on the rainfall map over northern Senegal. The rainfall histogram shows that large rainfall was experienced over this region in 2010, while 2002 was a relatively dry year. This can be used to explore specific years.

You can edit, create a new season and delete seasons.

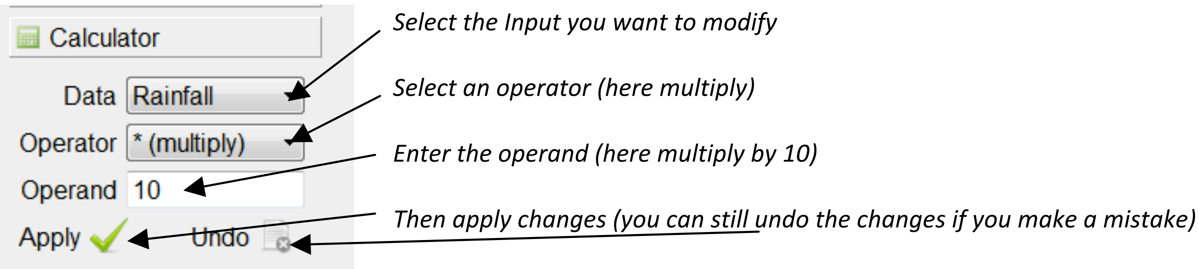
Let's start by defining a new long rainy season called "MJJASO" (May to October) which fits the rainfall mean seasonal cycle over Senegal. To do this, click on the green plus icon and define the season name as "MJJASO", then for the start you can use the calendar icon on the right, or manually edit it in the text box, and fix the start date to 1st May. Do the same thing for the end by setting it to 31st October and click "OK". Do not forget to click on Apply changes once you have finished. Once defined, the season MJJASO will now appear in the season pulldown menu. You can use the orange minus icon to delete it later if you wish.



You can also create a season called "Annual" by setting the start to 1st January and the end to 31st December. Do not forget to apply changes. Now annual averages are depicted for all inputs and all outputs on the time series and for the map. In summary DMC allows you to visualize mean seasonal cycles averaged for the whole time period, the seasonal average and annual averages for any given year.

Calculator:* *shortcut CTRL+SHIFT+E

In the tool box click on the "Calculator" tab, or in the tool bar click on the green calculator icon or in the menu bar: Tools->Climate data calculator.

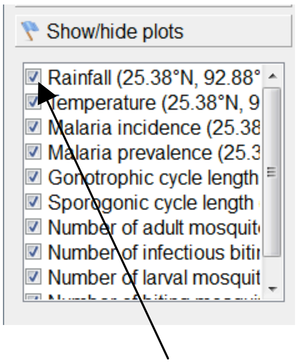


This tool allows you to modify, for instance, the units of the input datasets (for this example rainfall and temperature) by applying different operators (+ - * /) and operands. The LMM expects daily **rainfall** in **mm** and daily **temperature** in **°C** as inputs**.** The data you are actually using in this example already have the proper units. But if you started with rainfall in meters and temperature in degrees Kelvin, you may multiply (*) rainfall by 1000 to get mm or subtract (-) 273.15 to transform degrees Kelvin to degrees Celsius.

As an example choose Rainfall in the Data pulldown menu of the Calculator. Use the Operator "multiply" then set the operand to 10 (so multiply input rainfall by 10). Click on Apply changes. The values on the time series and the map have been multiplied and rescaled. As we already have proper units in our data, press the undo button to restore the original values.

Show/hide Plots: shortcut CTRL+SHIFT+H

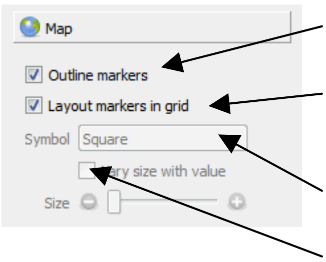
In the tool box click on Show/hide plots button or the flag icon in the icon bars or in the menu: Tools-> Show/hide plots.



If you uncheck/check the boxes associated with variable time series they will be hidden/shown in the graphical board. Uncheck the rainfall, and note that the rainfall time series histogram has been hidden, and then recheck it to make the plot reappear. This control also governs which time series histograms will be output with the File->Print… command.

Map markers properties: shortcut CTRL+SHIFT+M

In the tool box click on the Map tab or the earth icon in the icon bar or in the menu: Tools->Edit Map markers. This tool allows you to interact with the map shown in the graphical board.



***Outline markers**: add an outline to each node marker.*

***Layout markers in grid**: Constrain spacing of the markers on the map to make it look more like a grid.*

***Symbol**: Change the type of symbol (square by default, triangle, circle…)*

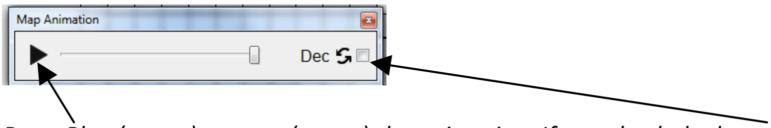
***Vary size with value**: Change the marker size as a function of the related input/output value, and then use the size slider to apply the factor.*

Tick the box "Layout markers in grid". Now the map looks more like a gridded raster. Note that you can experiment with the aspect ratio on the plots. In between each window pane (there are three panes – the map, the input plots and the output plots), move your mouse pointer slowly. A double arrow will appear. Left click and drag to modify the aspect ratio of the map plot until you find something you like. Now uncheck "Layout markers in grid" and check the "Vary with size with value" box. Change the symbol to circle then play with the size slider to visualize rainfall value for the month of June (first you need to reapply "climate averaging" in the "Start Date and averaging" tool box). You can quickly see that the largest rainfall occurs over southern and especially, southwestern Senegal in June. You can then experiment with the different marker settings.

Once finished, reset the symbol to square and recheck the box "Layout markers in grid". You can also show the numeric values on the map, for this use the Show/hide map marker value icon or in the menu: View->Show map values. Now move your mouse over the map, values will appear near the mouse pointer. Click again to disable this function.

Map animation:  **_shortcut CTRL+SHIFT+A_**

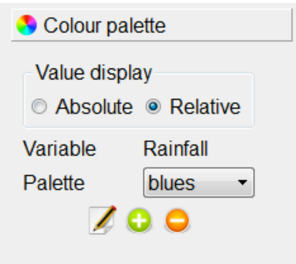
Click on the animation icon in the icon bar or in the menu: Tools->Map animation. This allows you to animate the map for any time series variable shown in the graphical board. You can change the animation speed in the Preferences (see Preferences section).



Press Play (pause) to start (pause) the animation. If you check the box on the right, the animation will loop.

Color palette:  **_shortcut CTRL+SHIFT+C_**

In the tool box click on the Colour palette tab or the colored disk icon in the icon bar or in the menu: Tools->Edit colour bar. This allows you to edit, create and delete color palettes for the map.



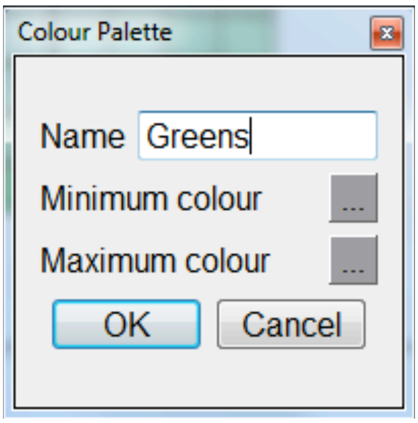
Value display: *Display all plot values (for both the map and the histograms) as relative (min and max on the plots vary as a function of the time step) or absolute values (min and max are fixed to the same value for all time steps).*

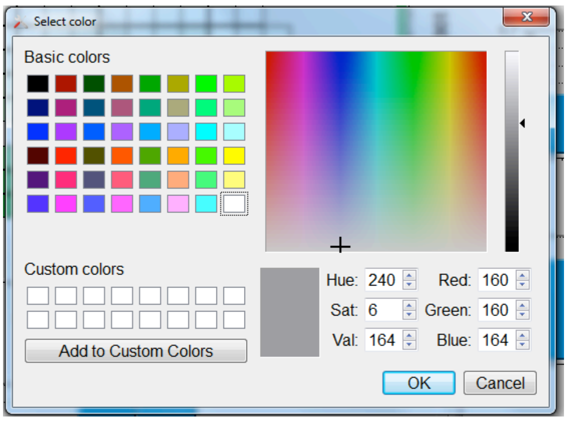
Variable*: the current time series variable you have selected.*

Palette*: Two palettes are defined by default, one ranging from white to blue, applied to rainfall and one from white to red for temperature.*

*You can then choose, edit, create, or delete a color palette for each variable. The palettes are saved in the *.dmc project file.*

Example: Click on the green plus button and create a new palette called "Greens".

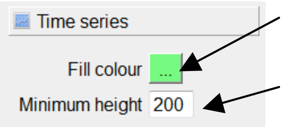




Click on a colour button "…" to open the colour selection dialog. As a minimum value select white, then "OK", and for the maximum pickup a dark green (using Basic colors or the color matrix on the right). Once you have finished click "OK". The new color palette is now available in the palette box and you can use it to depict rainfall in the map (for example). Basic HSV / RGB palettes can be edited. The colour selection tools look different on different operating systems – here we show the Windows tools.

Time series: shortcut CTRL+SHIFT+T

In the tool box click on the Time series tab or the Time series icon in the icon bar or in the menu: Tools->Edit time series style. This allows you to modify the time series style (height, filled color, etc).



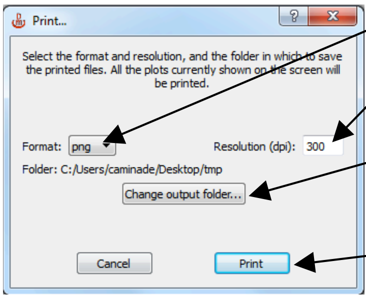
You can change the fill color of the histograms (works like defining a color palette)

and change the height of all time series in the graphical board.

As an example, change the time series fill color with the color you like the most and then set the minimum height value to 100. Once you tested this please reset the minimum height value to 200.

Print plots: i.e. export graphic images: shortcut CTRL+P

In the menu: File->Print…. This allows you to export the graphics displayed in the graphical board as images (use the Show/Hide toolbox to select a subset of the plots if you don't want to export all of them). Different formats are available (*.jpg, *.png, *.gif, *.tiff, *.bmp, *.ppm, *.xpm, *.pdf, *.ps, *.svg). This will allow you to import DMC images for further use in other documents (e.g. Word, PowerPoint…).



***Format**: Select the output image format (*.png, *.pdf, etc).*

***Resolution**: Change the output images resolution in dots per inches (dpi)*

***Change output folder**: Define the folder where the images will be saved to.*

*Then press the **Print** button to export the graphics as images.*

Running the LMM with DMC

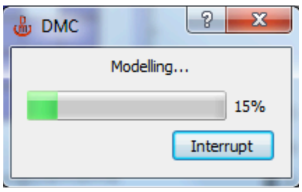
Now that you are familiar with the functionality of DMC it is time to use it to run a disease model: the Liverpool Malaria Model.

Remember **that DMC is just an interface into which can be plugged different disease (or other) models** driven by various inputs. The current version of DMC actually comes with the LMM, and other models will be incorporated later (Rift Valley Fever, Dengue, etc). So now we are going to run our first LMM simulation with DMC.

In the menu, click on Model, you can see that LMM is the model used in DMC by default; later on other models will be available and will be selected here.

To run the model: shortcut CTRL+R

In the menu, click on Model->Run… or click on the histogram icon in the tool icon bar.



You can then see the progress bar of your malaria simulation. You can press the Interrupt button at any time to stop the modeling process.

Once this is finished you should see the model outputs displayed on the right-hand side of the graphical board.

Click on the "Malaria incidence" time series, the map should display the malaria incidence pattern for Senegal. Using the tools we described above, display "Climate averaging" (using "Start date and averaging"), setup the color palette to Blues (in "Colour palette") and the click on the icon to create an animation. You can clearly see that the **SIMULATED** malaria season over Senegal is relatively short and ranges from September to November.

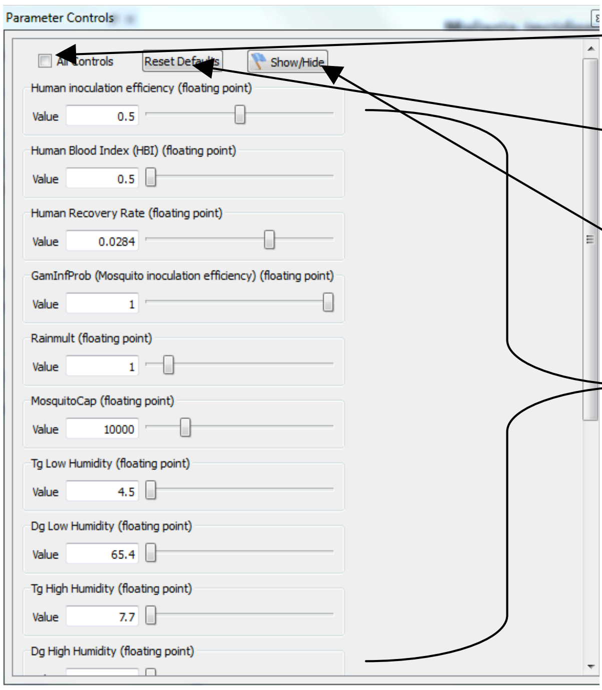
Now select the malaria season "SON" (in "Start Date and averaging"), do not forget to apply changes. Now the values are shown for each year for the seasonal average Sept-Oct-Nov. This corresponds to the simulated malaria season length you previously identified using the animation or by inspecting the malaria histograms on the right.

Click on a node located near 15N-15W on the map. You can see that the highest simulated malaria year is 2010, for which high rainfall was observed. Continue exploring the data. Look at differences between northern and southern Senegal…

Go to Preferences and check the box "Write model output to document". Save your document as "Senegal_LMM_standardsettings". You will be able to reopen the file later and your LMM simulation outputs will be restored. Note that the dmc file is now larger and uses more disk space.

Model parameter settings:* *shortcut CTRL+SHIFT+P

Click on the cog icon in the icon bar or in the menu: Tools->Model parameters. This allows you to modify the model parameter settings you are using (here for LMM) before running your simulation. A parameter controls dialog box will appear.



***All controls**: Allow user to modify all parameters (for advanced users).*

***Reset Defaults**: use the standard LMM parameter settings.*

***Show/Hide**: choose which parameters are displayed.*

This is the list of parameters that can be modified:

Example: The Human inoculation efficiency (default value 0.5)

At this stage you can change the different parameter values to those which seem more appropriate for your study area. When a parameter value is modified from its default value it is displayed in red. For more details about the different parameters see the associated LMM document.

As an example we are going to change the parameter settings according to recommendations and based on field data that have been provided by the Institut Pasteur in Dakar.

More realistic "Human biting rate" values were simulated when the rain multiplier factor was set to 0.07 and for "Adult mosquito survival" which fit the Craig-Martens survival scheme (Survival type = 3 in the parameter list).

Change the "Rainmult" factor to 0.07 (by typing it into the box or moving the slider). Check the "All Controls" to reveal the advanced tools. Then change the "Survival type" scheme by clicking on the "Limits", set the maximum to 3, then "OK". Then change the "Survival type" value to 3 (Craig Martens survival scheme instead of Martens scheme). Then uncheck "All Controls". The more advanced controls are intended for sensitivity tests, which can consume a lot of resources, and should only be used by advanced users.

Close this window and rerun the model.

Save the new file as "Senegal_LMM_IPDsettings". Explore the model outputs using the different functionalities of DMC. Look at the number of infectious biting mosquitoes on the time series. Reopen the DMC document created using standard settings i.e. "Senegal_LMM_standardsettings". Comment on the differences and the similarities.

To finish, reopen the DMC document "Senegal_LMM_standardsettings".

In Preferences check the "Write model output to files" box.

Rerun the LMM. Now DMC is asking you where you want to save the daily output of the LMM. Select or create a directory using the dialog shown. The output may require a significant amount of space available on your hard drive. Check that you have enough room before processing.

The values are outputted for each node in a specific folder named after the "node_number" (e.g. node000, node001, etc). Inside there is a sub-folder called "0" in which each variable outputs are saved (for LMM daily values) in various text files for all standard outputs of the model (Incidence, Prevalence, etc). Each "0" sub-folder contains a file called "_info.txt" that summerises all the parameter settings and location data for model run at that particular node.

These files can then be used to do further analysis on the daily outputs using Excel, Minitab, SPSS, etc.

Data used within this practical

The Senegal rainfall dataset is based on TRMM satellite rain gauge estimates (Huffman et al., 2007) and temperature files are based on the ERAINTERIM reanalysis dataset (Dee et. al., 2011, Uppala, 2008). Temperature has been interpolated to the TRMM native data grid.

Period: 1998:2010, daily resolution data
Spatial resolution 0.25x0.25 degrees covering the Senegal domain i.e. [10.5N-17N, 18W-11W]

Details:
Daily rainfall is derived from the Tropical Rainfall Measuring Mission (TRMM) dataset (3b42 version 6, 0.25° spatial resolution). The TRMM product is a joint satellite project between NASA and JAXA designed to improve observations of precipitation over the tropics (23). The mission incorporates several instruments, including a microwave imager, radar and visible-infrared scanner. The final daily product is derived from a combination of TRMM data and other satellite infrared observations (e.g. Meteosat, GMS, GOES and NOAA-12).

The user should cite and acknowledge these datasets when they use the related DMC examples; if there is any publication related:

References:

Huffman, G.J., R.F. Adler, D.T. Bolvin, G. Gu, E.J. Nelkin, K.P. Bowman, E.F. Stocker, and D.B. Wolff. (2007): The TRMM Multi-satellite Precipitation Analysis: Quasi-Global, Multi-Year, Combined-Sensor Precipitation Estimates at Fine Scale. J. Hydrometeorol., 8: 38-55.

Uppala, S., D. Dee, S. Kobayashi, P. Berrisford, and A. Simmons (2008): Towards a climate data assimilation system: Status update of ERA-Interim, in ECMWF Newsletter, 115:12ñ18, European Centre for Medium-Range Weather Forecasts, Reading-UK.

Dee et al., 2011: The ERA-Interim reanalysis: configuration and performance of the data assimilation system. Quat. Jour. Roy. Met. Soc., 137:553:597.

More details about the ECMWF ERAINTERIM product at: http://www.ecmwf.int/research/era/do/get/index
More details about the TRMM rainfall satellite product at: http://trmm.gsfc.nasa.gov

References

Ermert, V., Fink, A.H., Jones, A.E., Morse, A.P. (2011a) Development of a new version of the Liverpool Malaria Model: part I - refining the parameter setting and mathematical formulation of basic processes based on a literature review. Malaria Journal,10(35),pp. http://www.malariajournal.com/content/10/1/35

Ermert, V., Fink, A.H., Jones, A.E., Morse, A.P. (2011b) Development of a new version of the Liverpool Malaria Model. II. Calibration and validation for West Africa. Malaria Journal,10(62),pp.
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Ermert V, Fink AH, Morse AP, Paeth H (2011c) The Impact of Regional Climate Change due to Greenhouse Forcing and Land-Use Changes on Malaria Risk in Tropical Africa. Environmental Health Perspectives doi:10.1289/ehp.1103681.
http://ehp03.niehs.nih.gov/article/fetchArticle.action?articleURI=info%3Adoi%2F10.1289%2Fehp.1103681

Jones, A.E. and Morse, A.P. (2010) Application and Validation of a Seasonal Ensemble Prediction System Using a Dynamic Malaria Model. Journal of Climate,23(15),pp.4202–4215
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Appendix A: The Liverpool Malaria Model

A1 Suggested LMM parameter settings

a) Floating point parameters

Name	Default Setting	Ermert (2011) Setting	Definition/Notes
DISEASE TRANSMISSION			
Human inoculation efficiency	0.5	0.3	Probability of human infection given an infectious bite
Human Blood Index (HBI)	0.5	0.8 (0.4 incorporating adult/child conversion rate)	Proportion of bites taken from humans
Human Recovery Rate	0.0284	0.0050	Proportion of human population which return from infectious to susceptible, per day
GamFrac	N/A	0.5	Proportion of humans with gametocytes in their blood

GamInfProb (Mosquito inoculation efficiency)	1.0	0.2	Probability of mosquito infection given an infectious bite
Rainmult	1.0	N/A	Rainfall multiplier relating number of eggs per female to dekadal rainfall in mm
MosquitoCap	10000.0	400.0	Upper limit applied to number of female mosquitoes laying eggs.
LARVAL MOSQUITOES			
LarvalRateFactor	1.0	0.0	Multiplicative factor used for rainfall term in computing larval survival rate.
LarvalRateOffset	0.0	0.825	Offset added to rainfall term in computing larval survival rate.
FuzzyEgg: 9 : U1 10 : S1 11 : U2 12 : S2	N/A	 0 10 10 500[1]	Parameters governing fuzzy logic process for egg laying.
FuzzyLarvae: 13 : U1 14 : S1 15 : U2 16 : S2	N/A	 0 10 10 500	Parameters governing fuzzy logic process for larval survival.
ADULT MOSQUITOES			
Gonotrophic Cycle Survival	N/A	N/A	When the Lindsay-Birley mosquito survival scheme is invoked, the proportion of mosquitoes surviving each gonotrophic cycle.
Tg Low Humidity	4.5	4.5	Gonotrophic cycle threshold - low humidity (^oC)
Dg Low Humidity	65.4	65.4	Gonotrophic cycle length - low humidity (degree days)
Tg High Humidity	7.7	7.7	Gonotrophic cycle threshold - high

[1] Fuzzy parameter names are labelled here to be consistent with those used in the current version of the model but actually they are not consistent with terminology usually used for fuzzy logic modelling (U1,S1,S2,U2).

			humidity (^{o}C)
Dg High Humidity	37.1	37.1	Gonotrophic cycle threshold - high humidity (^{o}C)
Rt	10.0	10.0	Dekadal rainfall threshold (mm) for low/high humidity
Ts	18	16	Sporogonic cycle length (degree days)
Ds	111	111	Sporogonic cycle threshold (^{o}C)
BayohSurvivalShift	N/A	N/A	Fractional offset applied in Bayoh survival scheme.
DrySurvivalShift	0.0	-0.1	Parameter governing mosquito survival at the end of the season.
RainSeasonThresh	0.0	10.0	Dekadal rainfall below which survival shift parameter is applied.
MosTrickle	1.01	1.01	Trickle of infected mosquitoes added every 10 days
HumanTrickle	0.0	0.0	Trickle of infected humans added every 4 days

b) Integer parameters

Name	Standard Setting	Ermert et al (2011) Setting	Definition/Notes
Survival type	0	3	Survival Scheme 0: Martens 1: Lindsay/Birley 2: Bayoh 3: Craig version of Martens
EggFunc	0	2	Functional form used for egg laying: 0: Linear 1: Logarithmic 2: Fuzzy Logic
LarvalScheme	0	1	Functional form used for larval survival 0: Original form (rainfall function tending to 1 for high rainfall, 0.5 for low rainfall)

			1: Fuzzy logic function
MosMatureAge	15	12	Age in days at which larvae reach maturity
HumanInfectiousAge	15	20	Number of days after infection at which humans are infectious

A2 Model output variables

The current LMM outputs are:

- Incidence (malaria cases per 100 people)
- Prevalence (proportion of the human population infectious)
- Gonotrophic cycle length in days
- Sporogonic cycle length in days
- Total number of adult mosquitoes
- Total number of infectious mosquitoes biting at a given timestep
- Total number of larval mosquitoes
- Total number of mosquitoes biting at a given timestep.

A3 Structure of the LMM

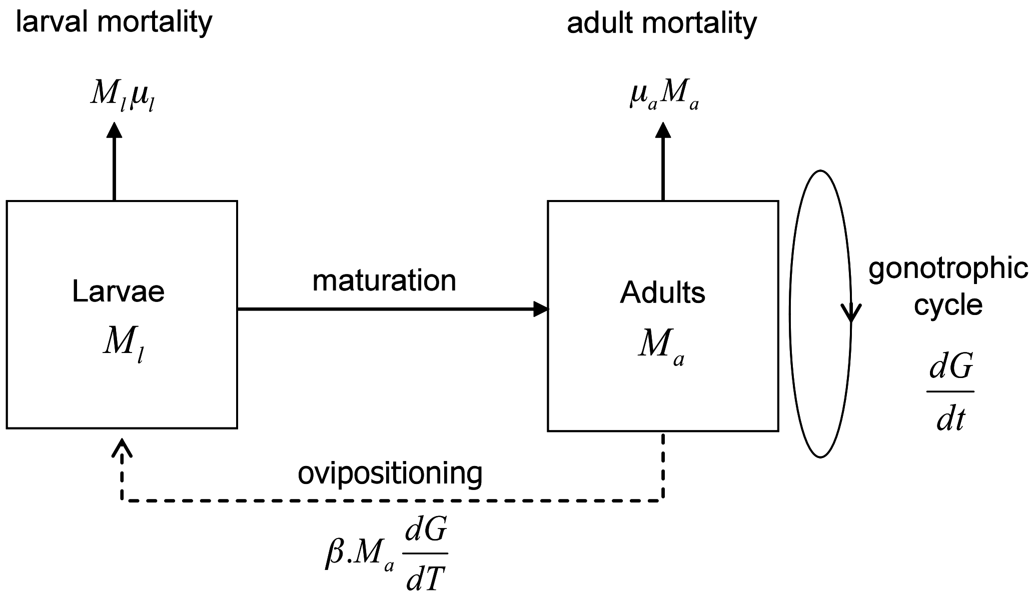

Figure A1 *Mosquito population component of LMM.* The population is divided into immature (larvae) and mature (adult) categories, M_l and M_a. Larval mortality occurs at a rate μ_l and adult mortality at a rate μ_a. New larval stage mosquitoes enter the population as eggs, with ovipositioning occuring at a rate dependent on the size of the adult population M_a together with rate of progression of the gonotrophic cycle $\frac{dG}{dt}$ and the number of eggs laid per mosquito per cycle, β. The maturation rate from larvae to adults depends on the variable larval mortality μ_l experienced during the larval stage and the fixed larval development period l_d.

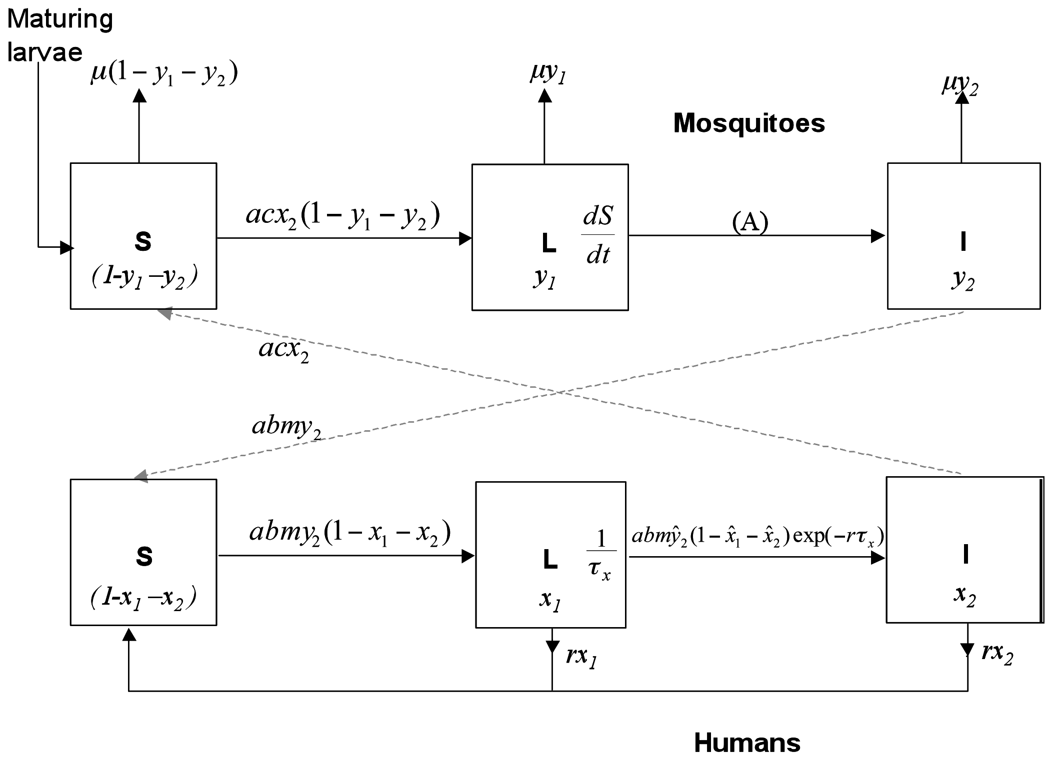

Figure A2 *Illustration of malaria transmission component of LMM, showing susceptible (S), latent (L) and infectious (I) classes for each population: mosquitoes (y) and humans (x).*

Instantaneous rates of transfer between the classes can be expressed in terms of the model parameters and the proportion of population in each class at time t or t-τ_x . The rate of transfer (A) from latent to infectious class for mosquitoes cannot be expressed this way if the rate of progression through the sporogonic class is variable.

Maturing larvae enter the susceptible class of the mosquito population at a variable rate according to the mosquito population model previously described. Rate of infection of each of the susceptible classes depends on the biting rate a, population susceptibilities b and c, vector density m (for the infection of humans) and the magnitude of the susceptible and infectious proportions of the relevant populations. The biting rate, a is variable, depending on the rate of progression of the gonotrophic cycle. The vector density, m, is also variable since the mosquito population is not fixed.