GLEAMviz.org

The Global Epidemic and Mobility Model

GLEAMviz SIMULATOR
CLIENT MANUAL

Version 6.0

CONTENTS

01

INTRODUCTION

This is the manual for the *GLEAMviz Simulator client*, which together with its server-side counterpart constitutes the *GLEAMviz Simulator system*. This system is a scientific application designed for researchers and students in the field of epidemiology who are interested in performing simulations of the spreading of infectious diseases on a global scale. It is based on the *Global Epidemic and Mobility model* (GLEAM), a stochastic computational model that integrates high-resolution demographic and mobility data, and uses a compartmental approach to define the epidemic characteristics of the infectious disease. More details on this model can be found on http://www.gleamviz.org and in Reference [1].

The client application is used to configure the simulations, to submit them for execution by the simulation engine on the server, and to retrieve and visualize the numerical results. The client consists of a few major components and windows: 1) the *Simulation*

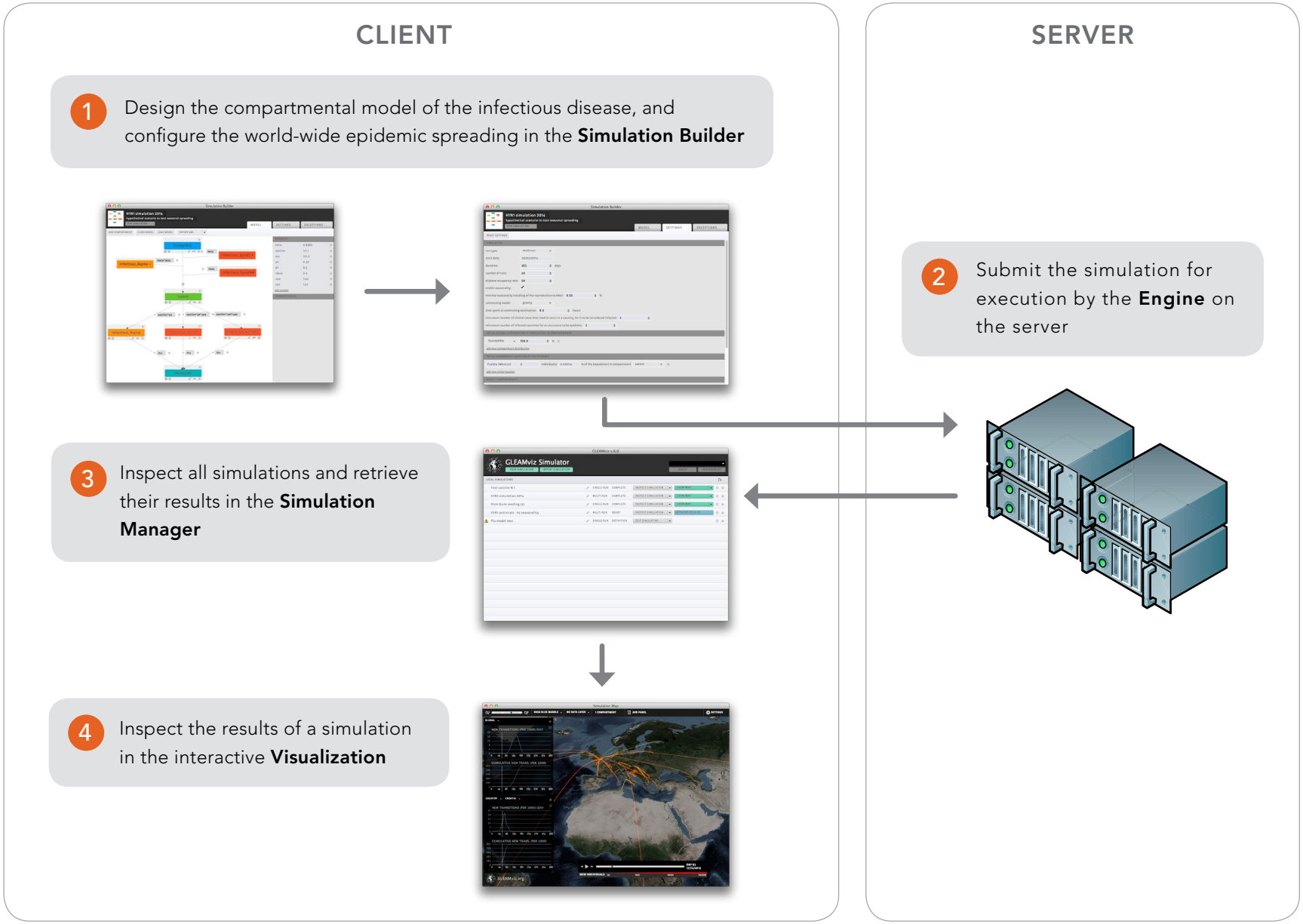

Figure 1.1: Workflow overview and the role of the client and server components.

Manager; 2) the *Simulation Builder*; and 3) the visualization components. Each of these components is described in more detail in the following chapters. The main workflow and the role of the components in this workflow are outlined in the diagram in Figure 1.1.

The usage of the Simulator tool requires users to perform a free registration, and to authenticate on the GLEAMviz server before submitting simulations for execution.

For more information about the *GLEAMviz Simulator* system please refer to the project's web-page: http://www.gleamviz.org/simulator.

1.1 RELEASE NOTES

The GLEAMviz Simulator system version 6 features a major update of the model data structure. Population data have been adjourned, as well as mobility data, and the subpopulations' definition has been revised. Long-range human mobility is now simulated using recent records about flight bookings, providing an improved description of the origin-destination paths of individuals travelling through the airline transportation network.

Due to this substantial adjournment version 6.0 is not compatibile with version 5.1 and former versions. It's not possible to load into the new client the old simulation, though it's still possible to import their model and definition.

1.2 LICENSE

There are two distinct editions of the *GLEAMviz Simulator client*: the *Public Edition*, which is publicly accessible but has a number of limitations, and the *Unlimited Edition*.

The *Public Edition* of the software application is distributed with the Software-as-a-Service (SaaS) paradigm and is freely usable according to the conditions of use reported below.

The full system setup, including the server application, can be requested by public institutions and research centers; conditions of use and possible restrictions will be evaluated specifically. If interested, please contact us at: info@gleamviz.org.

1.3 CONDITIONS OF USE

All material obtained directly from the simulation products of the *GLEAMviz Simulator*, or further processed, can be published by providing the appropriate credit to the website of the project (www.gleamviz.org) and the following publications:

1. **The GLEAMviz computational tool, a publicly available software to explore realistic epidemic spreading scenarios at the global scale.** W. Van den Broeck, C. Gioannini, B. Gonçalves, M. Quaggiotto, V. Colizza, and A. Vespignani. *BMC Infectious Diseases* **11**, 37 (2011).
2. **Seasonal transmission potential and activity peaks of the new influenza A(H1N1): a Monte Carlo likelihood analysis based on human mobility.** D. Balcan, H. Hu, B. Gonçalves, P. Bajardi, C. Poletto, J. J. Ramasco, D. Paolotti, N. Perra, M. Tizzoni, W. Van den Broeck, V. Colizza, and A. Vespignani. *BMC Medicine* **7**, 45 (2009).
3. **Modeling the spatial spread of infectious diseases: The Global Epidemic and Mobility computational model.** D. Balcan, B. Gonçalves, H. Hu, J. J. Ramasco, V. Colizza, and A. Vespignani. *Journal of Computational Science* **1**, 132 (2010).

1.4 CLIENT INSTALLATION AND REQUIREMENTS

The GLEAMviz Simulator client is a stand-alone desktop application and can be installed on Windows (XP, Vista, 7, and later), Mac OS X (10.6 and later) and Linux (32-bit and 64-bit) operating systems.

To install the GLEAMviz Simulator client download the installer program from:

http://www.gleamviz.org/simulator/client/

and run it (make sure you have the permission to execute the installer program, according to your OS security settings).

The GLEAMviz client features a built-in updating mechanism that periodically checks for new software updates, and then prompts the user to download and install them when available.

The *Public Edition* of the GLEAMviz client is pre-configured in order to use the GLEAMviz server made available by gleamviz.org: there is thus no need to install and configure the server to use the client. However, in order to avoid an overload on this server, a number of limitations are enforced in the public client setup. Research groups interested in an unlimited version of the GLEAMviz system are invited to contact us at info@gleamviz.org.

To properly install the GLEAMviz Simulator client, at least 200MB of free disk space is required. Additional disk space will be needed to store locally the output of the performed simulations.

1.5 CREDITS

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THIRD PARTY LIBRARIES AND OTHER ASSETS USED IN THE GLEAMVIZ SIMULATOR CLIENT

World Health Statistics 2009
http://www.who.int/gho/publications/world_health_Statistics/en/index.html
International data base (idb)
http://www.census.gov/ipc/www/idb/
Blue Marble map by NASA's Earth Observatory
http://earthobservatory.nasa.gov
Qt development framework
http://qt-project.org
OpenSceneGraph graphics toolkit
http://www.openscenegraph.org
BitRock InstallBuilder
http://installbuilder.bitrock.com

02

USER REGISTRATION AND LOGIN

2.1 LOGIN SCREEN

The *Login screen* interface is shown at first when the GLEAMviz client is launched. The user is asked to authenticate on the system by filling an input form with:

- username
- password

Three additional links are present in the Login screen:

- **register:** brings user to the *Register screen*, to create a new user
- **proceed offline:** brings user to the *Simulation Manager* without authenticating (local simulations can still be accessed)
- **forgot your password?:** brings user to the password reset interface

2.2 REGISTER SCREEN

The *Register screen* interface is used to create a new user's profile on the GLEAMviz system. An input form with the following fields is shown:

- username
- email
- password
- confirm password

Once the user completes the form, a request is sent to the server to validate the input (for example to check that the chosen username is not already taken). If some fields are not valid the user is shown an error message, otherwise a confirmation message is shown. Upon a valid registration, the user is sent an email to the given address, with a link to follow to confirm the registration request and activate the user account.

2.3 FORGOT PASSWORD

To recover a forgotten password, the user has to insert the username and the email given at registration in this form; upon submitting the form, the user will be sent an email with a new valid password to be used for authenticating. Once logged in, the user will be able to change the password by using the standard interface (see section 3.1.1).

03

SIMULATION MANAGER

The Simulation Manager window (shown in figure 3.1) is opened after the user performs a successful login, or when the user selects the 'proceed offline' option from the Login screen. This window consists of a menu bar and a list of the user's simulations, organized in different sections.

3.1 MENU BAR

The menu bar contains two pairs of buttons and a drop-down menu.

The buttons on the left are related to simulations.

- **New simulation:** opens the Simulation Builder component, which is used to design a new simulation and execute it.
- **Import simulation:** opens a dialog window to load a simulation definition from the file system.

The right ones refer to the software application in general.

» **About:** opens a credits screen.

» **Preferences:** opens a configuration window. See section 6 below for more details.

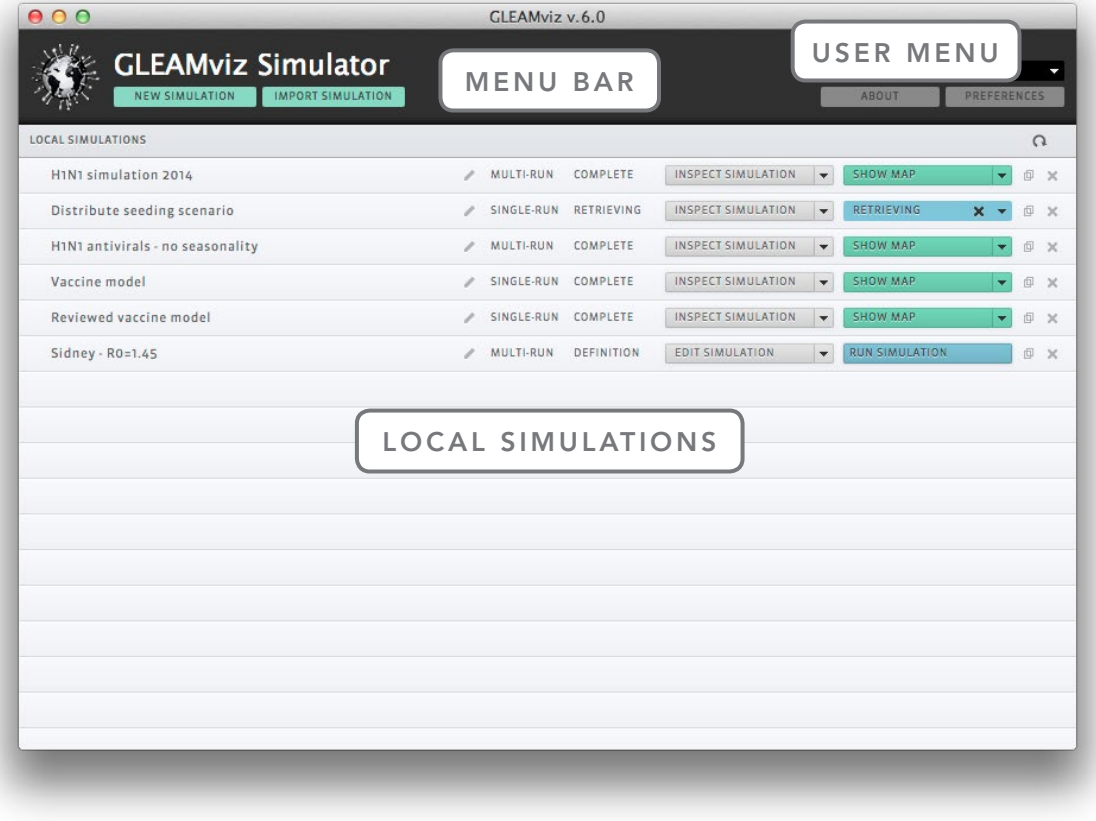

Figure 3.1: Main window with the menu and the simulations' list

3.1.1 USER MENU

The User menu is located above the right side buttons and provides the following options (for authenticated users):

- **Change email:** to modify the user's email
- **Change password:** to modify the user's password
- **Log off:** to log-out from the server and use GLEAMviz Simulator in offline mode.

The change email and change password interfaces ask the user to insert twice the new email address or the new password.

For non authenticated users, the User menu displays the following options:

- **Register:** to move to the Register screen
- **Log in:** to move to the Login screen

3.2 SIMULATIONS MANAGEMENT

The *Simulation Manager* window (see figure 3.1) lists the simulations that the user has access to. It is organized in sections relative to the logical position of the simulations.

- **Local simulations:** lists the locally available simulations that the user has created so far or that have been imported from other sources.
- **Simulations on GLEAMviz server:** lists the simulations that are available on the GLEAMviz server but are not present locally. This section is shown only if there are simulations on the server which are not present locally; it is useful when logging in with a client different from the one where the simulations were created, to access those simulations from multiple machines.

Each row of each section refers to one simulation, displaying information and actions available:

» **Title:** title of the simulation. Clicking twice on it (or clicking on the '*edit*' icon next to it) allows the user to edit the title. Hovering on the edit icon displays the id of the simulation.

» **Type:** displays the type of the simulation (either single-run or multi-run).

» **Execution status:** displays the execution status of the simulation (see section 3.2.1).

» **Simulation Definition menu:** provides access to actions related to the simulation definition. See section 3.2.2.

» **Simulation Results menu:** provides access to actions related to the execution and the results of a simulation. See section 3.2.3.

» **Clone Simulation button:** opens the *Simulation Builder* with a new clone of the currently selected simulation.

» **Remove Simulation button:** clicking this button deletes the selected simulation. Associated results will also be deleted. This action cannot be undone.

3.2.1 SIMULATION STATUSES

A simulation listed in the *Simulation Manager* can be in one of the following statuses, relative to its execution and to the availability of the results:

» **definition:** the simulation has been created and defined but has not been submitted for execution. If a simulation has not been fully defined (some parameters are missing or some inconsistencies have been detected in the model) an alert icon is shown at the left of the title, and the execution is inhibited.

» **running:** the execution request has been issued and has been accepted by the server.

» **ready:** the simulation execution has been completed and the output data are ready to be retrieved.

» **retrieving:** the simulation's output data are being downloaded from the GLEAMviz server.

» **paused:** the retrieval of the simulation's output data has been stopped by the user.

» **complete:** the simulation is complete and the output data are locally available.

» **failed:** the simulation execution failed for some reason.

» **aborted:** the simulation execution has been interrupted by the user.

For single-run simulations, the results will be immediately retrieved and, depending on the configuration settings, the Geographic Mapping Window will open as soon as the client starts to receive output data from the server. For multi-run simulations, the server will be regularly polled in order to check the status of the execution of pending simulations, so to show the user when the results are ready.

3.2.2 SIMULATION DEFINITION MENU

The simulation definition menu provides access to actions related to the simulation definition:

» **Edit / Inspect simulation:** for simulations that have not yet been submitted, the *Edit Simulation* button is shown. Clicking on this button opens the *Simulation Builder* in full editor mode, allowing the user to edit the compartmental model and all the simulation parameters. Once a simulation has been submitted, it can no longer be modified (except for its name and notes). In this case, the *Inspect Simulation* button is shown. It opens a read-only version of the *Simulation Builder*, which shows the model and all the simulation's parameters. It is possible to visualize and save the model and configuration but not to modify it.

» **Export simulation definition:** exports the simulation definition to an XML file.

This file can later be used as the template for a new simulation or it can be shared with other users. Sharing the definition file with others allows them to run a simulation with the same parameters.

3.2.3 SIMULATION RESULTS MENU

The simulation results menu provides access to actions related to the execution and the results of a simulation. Different options are available depending on the execution status.

- **Run simulation:** submits the simulation for execution to the GLEAMviz server.
- **Stop simulation (multi-run):** enabled when the execution of the selected simulation is ongoing. Clicking this button allows the user to stop the execution of the simulation.
- **Stop simulation (single-run):** enabled when the execution of the selected simulation is ongoing. Clicking the X icon button stops the execution of the simulation, selecting the drop down menu (down arrow icon) allows the user to access three different visualizations (Map/Globe/SPaTo).
- **Retrieve results:** this button is shown for completed simulations. It allows the user to download the results from the server
- **Retrieving:** is shown while the results of a completed simulation are being downloaded. Clicking the X icon button stops the data retrieval, selecting the drop down menu (down arrow icon) allows the user to access three different visualizations (Map/Globe/SPaTo).
- **Resume retrieving:** is shown if the user stopped the data retrieval. Allows to continue the download of the results.
- **Show map / Show SPaTo / Show globe:** these options allow the user to access three different visualizations (opening a new window). This button is only shown

when simulation results are present.

» **Export results:** once the results have been fully retrieved, this button allows the user to export the data, including relevant meta-data and the simulation definition, to a folder. The formatting of this data is detailed in section 8.

» **Clear results:** this button allows the user to remove the locally stored results from the machine. If the simulation is no longer available on the server, this action resets the simulation to the 'definition' status (and cannot be undone), otherwise it is set to the 'retrieve results' status.

04

SIMULATION BUILDER

The *Simulation Builder* window is used to design a simulation, from the compartmental model to the global settings and optional time-dependent exceptions.

The simulation editing window provides a menu header and a number of tabbed panels.

» **Menu header:** The header contains information and actions related to the simulation as a whole. It contains the simulation name and notes (both editable) and the ***Run Simulation button.*** This button is enabled when the simulation definition is consistent and error-free. It allows the user to submit the simulation to the server for execution. The submitted simulation will be added to the *Simulation Manager*'s list and the *Simulation Builder* window will be closed.

» **Panels:** Below the header, three tabbed panels labeled "Model", "Settings", and "Exceptions" cover three aspects of setting up a simulation. When the information provided in a panel is inconsistent, the "Concerned" tab will

display a warning icon. Hovering the mouse over this tab will display the related warnings in a pop-up.

The panels are described in detail in the following sections.

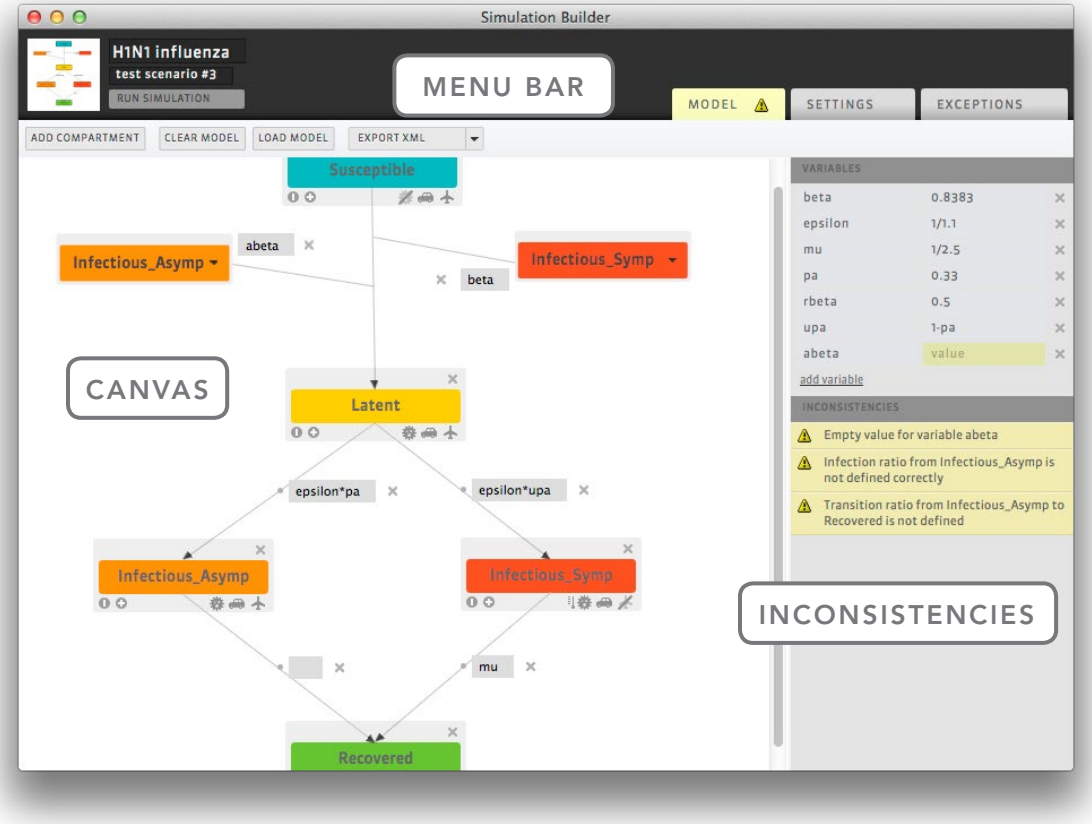

Figure 4.1: Compartmental Model Builder

4.1 MODEL BUILDER PANEL

The *Model Builder* is used to design the *compartmental model* of the infection dynamics. Figure 4.1 identifies the five components of the compartmental Model Builder interface:

- **Menu bar:** located at the top of the window. It contains buttons to add compartments to the model, to load a model from a file, to clear the model by removing all elements, and to export the model to a file, either as a loadable XML or as an SVG representation of the model diagram.
- **Canvas:** the *canvas* contains an editable diagram of the compartmental model. It allows the user to move or remove compartments; configure compartment settings; add or remove spontaneous transitions and infection transitions; set transition rates as constant values or simple functions of variables; and add, change, or remove infection source compartments. See below for more details.
- **Variables list:** this component lists the variables (*name = value pairs*) referenced in the model. New variables can be added by clicking the ***add variable*** button. Variables can be removed by clicking the cross button on the right-hand side of the variable entry in the list. The name and value of the variables can be edited in the variables list. The values can be algebraic expressions that include references to other variables. Variable names or values with errors are marked in yellow and provide an explanation of the error when hovered over with the mouse. See section 7 for more details on writing expressions.
- **Inconsistencies:** this component lists the inconsistencies in the model definition, as determined by the client. These inconsistencies need to be resolved before submitting a simulation.

4.1.1 COMPARTMENTS

Clicking the ***Add compartment*** button in the menu will add a new representation of a compartment on the diagram canvas. This compartment will initially have a default

name. This name can be changed by clicking on the name in the compartment's representation and entering a new one. Compartments can be repositioned by dragging on the gray area around the colored body of the compartment representation. The color of a compartment can be changed for ease of reference by selecting a color from the color list, which appears when the user clicks on the *change color* button on the compartment representation.

On the gray area below the compartment name, there are five icons that allow the user to add a transition to another compartment, mark the compartment as a carrier or a clinical case, and allow or disallow commuting and air travel for it. Figure 4.2 details the functionality provided by the compartment representation.

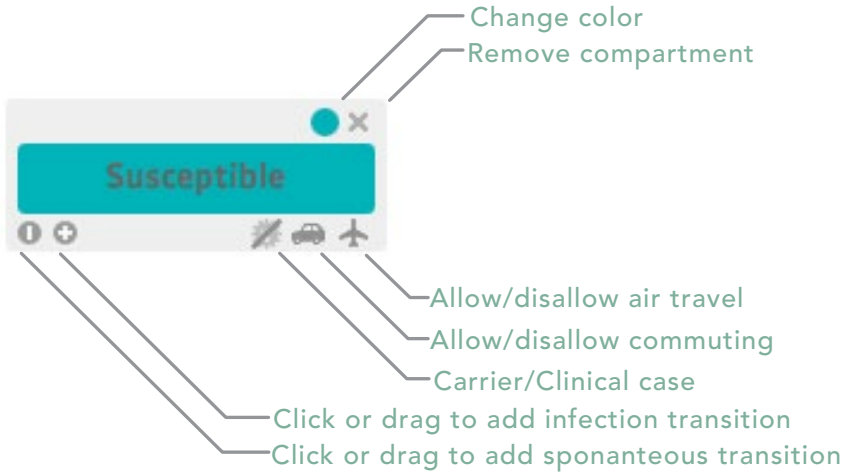

Figure 4.2: Compartment view

The Carrier/Clinical case icon is used to mark those compartments that are carrying the pathogen and may eventually lead to the disease transmission. It is important to

mark all compartments that might introduce the virus in a population as carrier, even if they have not yet transmitted the infection. For instance, the exposed compartment is a typical example of carrier, as exposed individuals will generally transition to an infectious state that could generate transmission of the disease in the population. A compartment is considered to be a carrier if the virus icon is not barred, and clinical cases are identified by double clicking when the thermometer symbol is shown by side of the virus symbol (see fig.4.1). At least one compartment among the infectious compartments must be defined as corresponding to a clinical case, and this is used by the GLEAM simulation engine to define the conditions for the detection of an outbreak in a given country (see section 4.2).

4.1.2 TRANSITIONS

There are two types of transitions: ***infection transitions*** and ***spontaneous transitions***. Transitions from one compartment to another can be added by dragging the corresponding icon from the source compartment to the target compartment (see Figure 4.2). Dragging a transition icon to an empty point in the canvas will result in the creation of a new compartment and a transition of the selected type connecting it.

When a susceptible individual comes in contact with an infectious one, he/she might contract the infection in accordance with a transmission rate defined by the user. This rate can be an algebraic expression that includes references to other variables. See section 7 for more details on writing expressions.

If the susceptible compartment is denoted by "*S*" and the infectious one is denoted by "*I*", the expected number of new infections generated under a homogeneous assumption in each sub-population is given by:

$$\beta I \frac{S}{N} \tag{4.1}$$

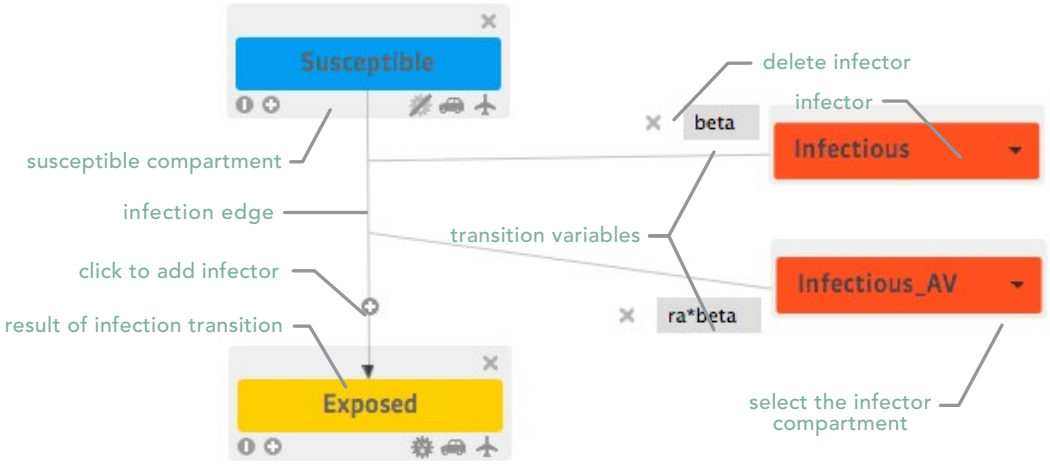

Figure 4.3: Compartment view GUI

where β is the transmission rate set by the user and N is the total population. Individuals can undergo spontaneous transitions from one compartment to another. Examples include the transition from latent to infectious individuals or from infectious to recovered individuals. The GLEAM simulation engine considers discrete individuals and all transition processes are stochastic, discrete, and modeled through binomial and multinomial processes. For more details, please refer to Ref. [1].

Figure 4.3 provides an overview of the components and functionalities provided for an infection process.

4.1.3 VARIABLES

The user can define one or more variables, which are name–value pairs or name–expression pairs. The transition rate expressions can reference these variables, and the value expression of one variable can reference other variables. These variables are defined in the variables panel on the right side of the Model Builder window.

The name of a variable must start with a letter and can only contain alphabetic, numerical, and underscore characters. The value can be an algebraic expression that includes references to other variables. Variable names or values that do not conform to these rules are marked in yellow. See section 7 for more details on writing expressions.

4.1.4 INCONSISTENCIES

Before a simulation can be submitted to the server its model must be free of inconsistencies. Any inconsistency that is detected by the GLEAMviz client is listed in the inconsistencies section of the GUI. A model can be saved/loaded to/from a *gvm* XML file if inconsistencies are present, but the simulation cannot be executed.

Examples of inconsistencies are undefined transition rates, invalid transition rate expressions, and circular variable dependencies (see section 7). Note that while the client can determine if a compartmental model is technically consistent, it cannot determine if it makes sense epidemiologically.

4.1.5 SAVING AND LOADING COMPARTMENTAL MODELS

The same compartmental model is often used in numerous simulations. Instead of having to recreate this model for each simulation, users can design it once and save it as a file that contains an XML representation of that compartmental model. When configuring subsequent simulations, the compartmental model can then be loaded from such a file and subsequently modified and extended.

The conventional extension for compartmental model files is *gvm*, from GLEaMViz model. The *gvm* files can be opened in any client and thus can be shared with colleagues. Note that it is also possible to open a *gvd* file (containing a simulation definition) or a *gvs* file (containing a simulation, with or without results) in which case the included compartmental model will be loaded.

4.1.6 EXAMPLES

Examples of compartmental models (with *.gvm* extension) can be downloaded from

http://www.gleamviz.org/simulator/models/. These examples can be imported into the Model Builder using the Load model button (see Fig. 4.1).

4.2 SETTINGS PANEL

The Settings panel is used to configure the simulation's general parameters, which define the basic scenario for the simulation that will be run by the GLEAMviz server.

On the menu bar, a button is shown:

» **Reset settings:** resets all the values to the application defaults.

The *Settings* panel interface (shown in figure 4.4) is divided into four sections: *Simulation*, *Initial assignment of population*, *Initial geographic location of the epidemic*, and *Result compartments*.

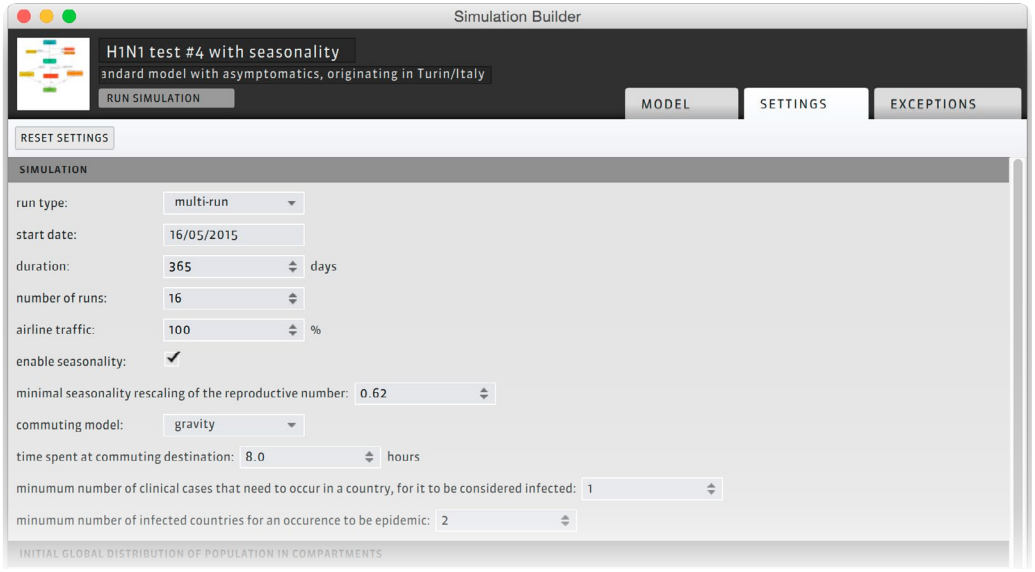

Figure 4.4: Simulation settings

4.2.1 SIMULATION

The Simulation panel collects settings concerning the global settings of the simulation:

» **Type:** single-run (SR) or multi-run (MR).
A *multi-run simulation* performs multiple simulations (runs) with the same model and settings, and it returns averages and confidence intervals calculated over the set of runs. A *single-run simulation* performs the simulation once. The returned results are the results from that one run and do not include confidence intervals. Unlike the multi-run, the results include data on the concrete transmission of infected individuals between cities, which can be shown as arcs in the visualization.

» **Start date:** the date at which the epidemic begins.

» **Duration:** the length of each simulation run expressed in days.

» **Number of runs (MR only):** the number of stochastic runs starting from the same initial conditions that must be performed and over which the statistics of the simulation results will be performed. Increasing this number results in improved statistics but also in longer computational time.

» **Airline traffic:** average percentage of passengers with respect to the number of bookings derived from flight data. The default value is 100%. For each simulated flight, the number of passengers is a stochastic variable sampled from a binomial distribution whose mean is given by the airline traffic value times the number of bookings.

» **Enable seasonality:** if this feature is checked, the GLEAM simulation engine will run simulations considering the seasonality effect on the infection transitions. Seasonality is modeled by rescaling the basic reproduction ratio R_0 by a sinusoidal function $s_i\,(t)$, such that:

$$s_i(t) = \frac{1}{2}\left[(\alpha_{max} - \alpha_{min})\sin\left(\frac{2\pi}{365}(t - t_{max,i}) + \frac{\pi}{2}\right) + \alpha_{max} + \alpha_{min}\right] \qquad (4.2)$$

where *i* refers to the hemisphere considered, following the standard approach adopted in the literature. In the tropical region, the scaling function is equal to 1.0. Along the year, the seasonality scaling function varies from a maximum rescaling, $\alpha_{max,}$ to a minimum rescaling α_{min}. α_{max} is set to 1.1, following previous approaches, whereas α_{min} is set by the user (see below). The full description of the seasonality modeling is reported in Ref. [1] and its Supplementary Information.

» **Minimal seasonality rescaling of the reproductive number:** this option is available only if seasonality is enabled (see above). The value corresponds to the minimum value of the rescaling of the reproductive number, due to seasonality.

» **Commuting model:** this option allows to specify which model shall be used while computing the number of commuters between neighbouring regions; three options are possible:

gravity model: the number of commuters moving from location *i* to location *j* is given by the gravity law with parameters estimated based on the real commuting data collected from more than 30 countries. According to the model, the number of commuters on any given connection is an increasing function of the populations at the origin and destination and a decreasing function of the distance between them.[1]

radiation model: the number of commuters moving from location *i* to location *j* is given by the radiation model whose input parameter is informed by the real commuting data collected from more than 30 countries. The number of commuters increases with the population at the origin and destination while it decreases with the total population in the surrounding region of the origin.[2]

1 Balcan D, Colizza V, Gonçalves B, Hu H, Ramasco JJ, Vespignani A: Multiscale mobility networks and the large scale spreading of infectious diseases. Proc. Natl. Acad. Sci. USA 2009, 106: 21484-21489.

2 Simini F, Gonzalez MC, Maritan A, Barabási AL (2012): A universal model for mobility and migratory patterns. Nature 484: 96-100.

» **Time spent at the commuting destination (hours):** the average number of hours spent by the commuters at the commuting destination. The default value used is 8 hours, corresponding to the average amount of working time in a day.

» **Minimum number of clinical cases that need to occur in a country (for it to be considered infected):** this parameter sets the condition for an outbreak in a country.

» **Minimum number of infected countries (for a global epidemic to be considered to occur):** this parameter sets the condition for the global outbreak. The default value is 2, which corresponds to the requirement that a second country be infected besides the country where the outbreak initially occurs.

4.2.2 INITIAL GLOBAL DISTRIBUTION OF POPULATION IN COMPARTMENTS

This section allows the user to specify the initial conditions for the population of each compartment defined in the model. Populations per compartment are expressed in percentages of the total. Different options can be defined: a fully susceptible population, conditions for partial immunity, etc. These initial conditions are extended to the whole set of sub-populations considered in GLEAM. Clicking the *add new compartment distribution* link will add a new compartment to the list, for which it is possible to define the initial population (see Fig. 4.5). By default, the first compartment added will contain the entire population. In case of multiple compartments, the user must adjust the population distribution in order to total 100%. All other compartments not

Figure 4.5: Initial distribution of population into compartments

listed in the window are set equal to 0. Compartments can be removed by clicking the *X* button on the right.

4.2.3 INITIAL GEOGRAPHIC LOCATION OF THE EPIDEMIC

This section of the simulation's setup panel allows the user to define the initial location and quantity of the infectious individuals. Please note that they need not be defined in the initial population assignment section (the previous one), which is a global setting valid for all the census areas worldwide. To add a new epidemic seed, the user can click on the ***add new initial location*** link. This will add a new line in the list, displaying default values for the epidemic origin. City and compartment of the seed can be selected from the corresponding lists (see figure 4.6). It is possible to add an arbitrary number of epidemic seeds or to remove a previously inserted one by clicking the *X* button on the right.

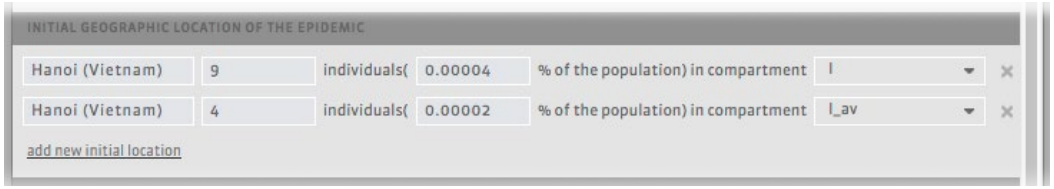

Figure 4.6: Initial geographic location of the epidemic

Infection seeds can be indicated in terms of number of individuals or fraction of the population of the selected basin (census area associated with the city). At least one infectious individual in one city/basin must be specified before proceeding to the next interface.

4.2.4 RESULT COMPARTMENTS OF INTEREST

The last section of the *Settings* panel requires selecting the compartments wanted as output, whose data will be shown in the Visualization Window and will be available for local download. The user can select one or more compartments (at most 5 for the

Public Edition) to be considered when retrieving and visualizing the results in this client. Depending on this selection, upon simulation completion, the user will be able to visualize the results for all or a subset of the compartments selected here.

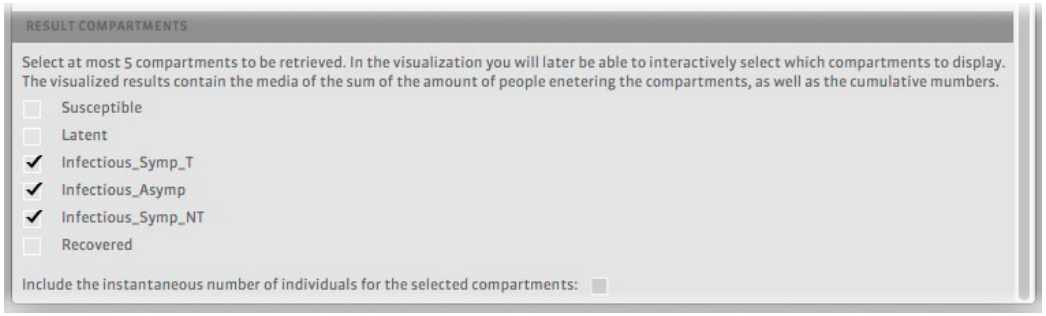

Figure 4.7: Result compartments

4.3 EXCEPTIONS PANEL

The *Exceptions* panel provides a way to specify time and space dependent exceptions or the variable values defined in the compartmental model. On the menu bar, two buttons allow the user to manage exceptions:

- **Add new exception:** lets users add exceptions to the current simulation.
- **Clear all exceptions:** removes all the exceptions defined for the simulation.

The exceptions are specified in terms of *rules*, or variable overrides. Each exception lets the user define an alternative value for one or more variables during a specific time-span and for a specific set of geographic units (cities, countries, etc. . .).

The simulation will use the given alternative variable values:

- from the selected start date up to and including the selected end date
- for all the city areas belonging to one of the specified geographical units

More than one rule can be specified for each exception.

On the title bar of each exception, the user can adjust the priority when multiple exceptions are defined: higher priority overrides lower priorities, in case of rule overlap.

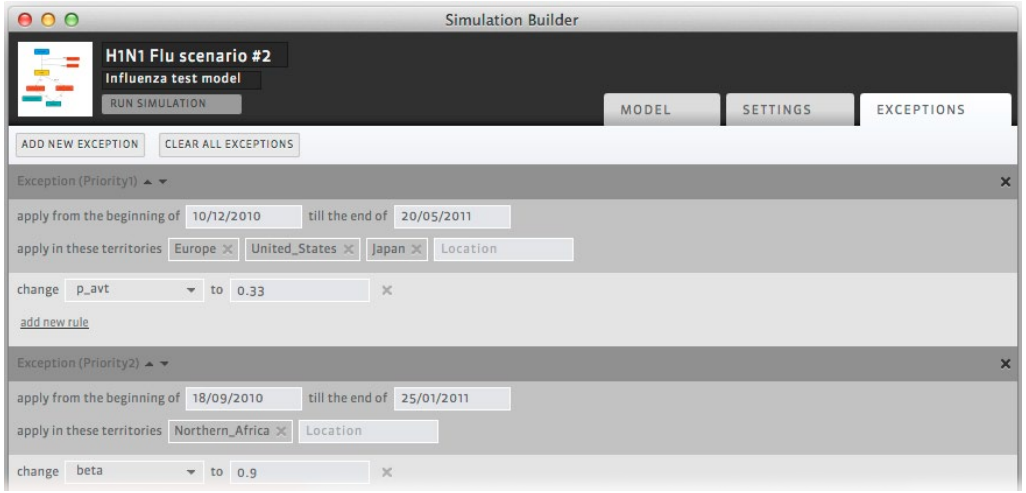

Figure 4.8: Time and space dependent exceptions

05

VISUALIZATION COMPONENTS

The Geographic mapping window is the main component of the GLEAMviz Simulator client that allows the user to see the results of a simulation. The window opens when the user clicks the ***Show map*** button in the *Simulation manager*. The drop down menu associated with the ***Show map*** button offers the chance to select two other data visualizations of the output: *Show SPATO* and *Show globe*, described respectively in sections 5.2 and 5.3.

For single-run simulations, according to the user's configuration settings, the Map Visualization Window is opened as soon as the simulation has been successfully submitted to the server. The visualization consists of a *Map* with the temporal and geographic mapping of the results, the *Map Control*, the *Play Control*, and a number of *Charts Panels*; all of these are identified in figure 5.1.

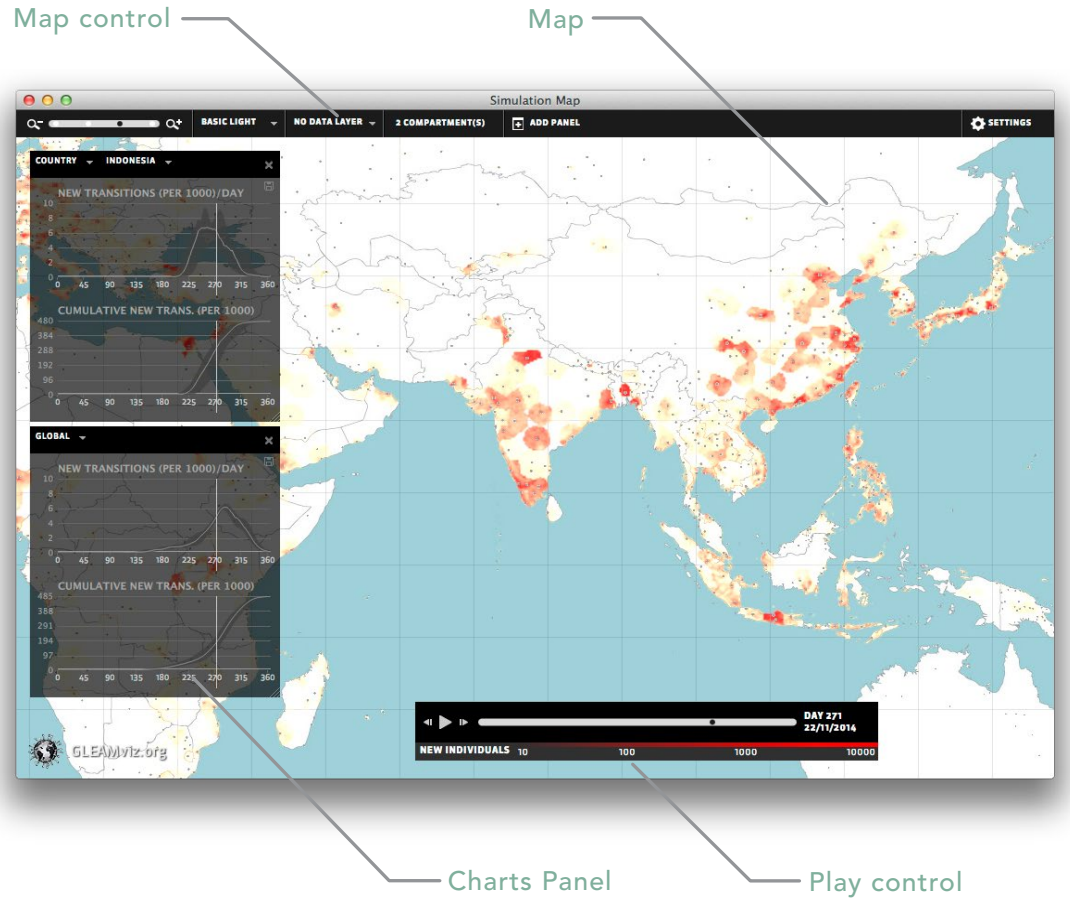

Figure 5.1: Annotated Visualization Window

5.1 GEOGRAPHIC MAPPING

The geographic mapping involves a zoomable multi-scale map onto which the results for the selected focus compartment(s) are geographically mapped. These focus compartments are chosen, from the list of result compartments selected in the *Simulation Builder* (see section 4.2.4), by means of the drop-down menu provided in the *Map Control*, as shown in figure 5.2. In this menu, the user needs to select the result compartments (at least one) for which the results should be shown and click on "Apply" to apply the selection. The mapping and charts will then show the summed results of the selected focus compartments. Note that initially the first "secondary" result compartment is selected as the sole focus compartment.

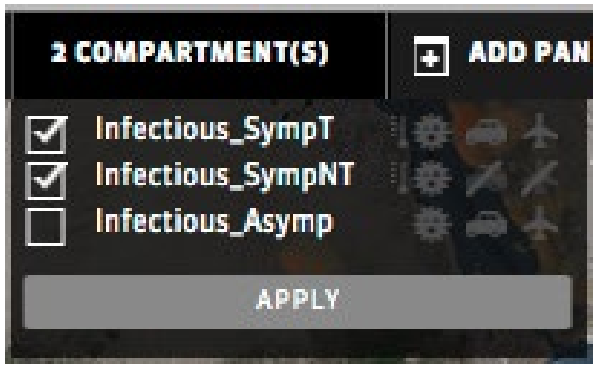

Figure 5.2: Visualization Window: focus compartments selection drop-down menu

For single-run simulations, the map shows (on top of the map base) the amount of people entering the selected focus compartments on the current day. For multi-run simulations, the corresponding median over the multiple runs is shown. By selecting the relative option in the map settings panel (Settings > Infection appearance > Cases: shown data) it is possible to visualize on the map the cumulative number of people that entered the selected compartments until the current day, switching between the two visualizations. These values are shown using the color scale shown in the legend of the *Play Control*, see figure 5.4. This color scale can be modified in the *Map Settings* (section 5.1.4).

It is also possible to show on the map some extra data that are used by the model but do not depend on the simulated scenario: the population density and the number of hospital beds and physicians per 10,000 inhabitants.

The *Map Control* (see figure 5.3) can be used to configure the visualization options by providing widgets to:

- zoom in and out of the map
- choose the map background (see section 5.1.1)
- choose the underlying data layer
- select the focus compartments
- add a new *Charts Panel* (see section 5.4)
- access the *Map Settings* menu

Panning can also be done by dragging the map with the mouse.

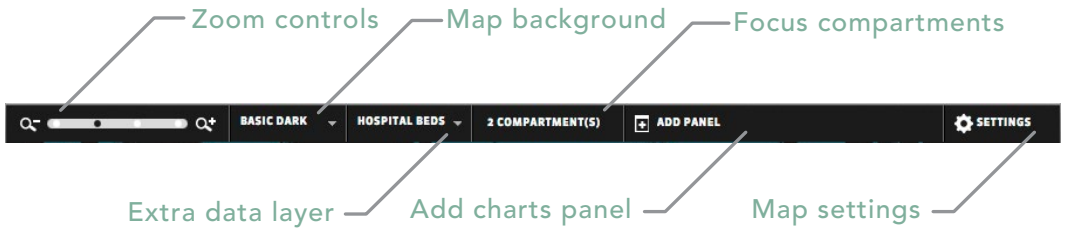

Figure 5.3: Visualization Window: Map Control details

At any given moment, the map shows the number of new cases or the number of cumulative cases (depending on the option selected in the Infection Data panel in the

Map settings) for one particular *Current day*, which is specified on the *Play Control*, as shown in figure 5.4. The time evolution of the epidemic is represented by showing the results of subsequent days, updating the mapping accordingly, and thus obtaining an animation. The user can use the *Play / Pause* button in the *Play Control* section to start or pause this animation. The marker in the timeline marks the current day. Drag this marker or click on the timeline to change the currently selected day. Use the buttons left and right of the *Play / Pause* button to go back or forward one day.

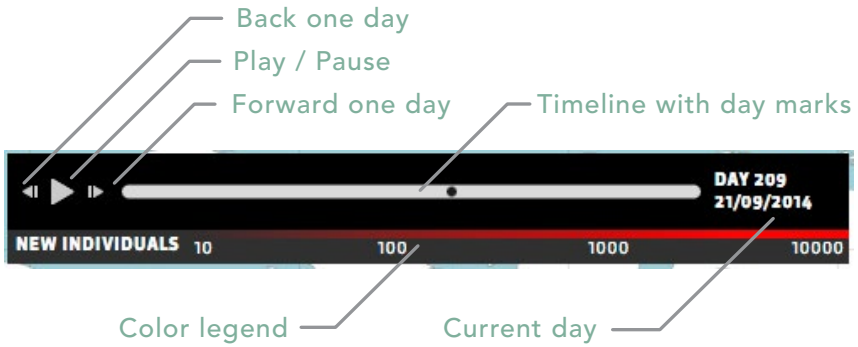

Figure 5.4: Visualization Window: Play Control details

When opening the Geographic mapping window by default one Charts Panel is shown, displaying the global data. See section 5.4 for details.

5.1.1 MAP BACKGROUNDS

Different map background types can be selected, by using the drop-down menu in the *Map control* or the map's context menu (right-mouse-click or ctrl-click on the map to open this menu). Figure 5.5 shows some background examples.

5.1.2 CITY INFO POP-UPS

When moving the cursor on the map, if hovering an area belonging to one of the modeled metapopulations that area is highlighted, and a small popup appears that displays the name of the corresponding city (and the airport code). Clicking on the highlighted basin area opens a larger pop-up like the one shown in figure 5.6. These city info pop-ups provide additional details about that city:

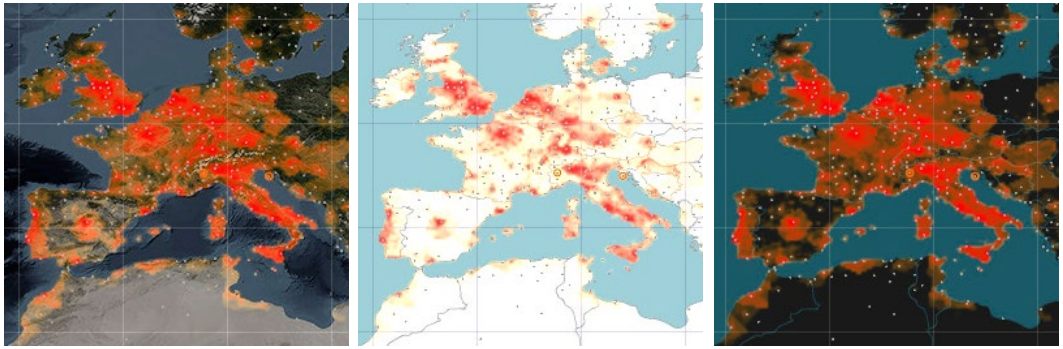

Figure 5.5: Visualization Window: Map background types from left to right: Blue Marble Map, Light Map, Dark Map

- the airport code
- the population of the city basin
- the country to which the city belongs
- the average number of hospital beds for 10000 inhabitants (when available)
- the average number of physicians for 10000 inhabitants (when available)
- the new and cumulative number of people in the currently selected focus compartments in this city on the current day
- the age distribution structure of the population in the city area (when available)

Use the *Close* button to close the pop-up or the *Show in new Charts Panel* button to open a new Charts Panel with this city as the context. See section 5.4 for more details on the Charts Panels.

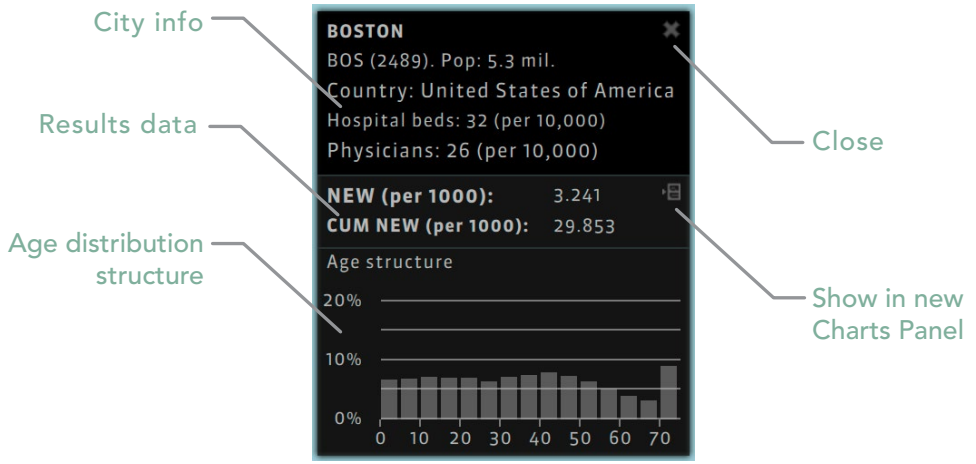

Figure 5.6: Visualization Window: City info pop-up

5.1.3 INFECTION TRANSPORT

For single-run simulations, the transportation of "seeding" individuals can be shown. A seed is the first occurrence of an individual belonging to the selected focus compartment(s) flying to a particular city. Seeding can only be shown for compartments carrying the infectious pathogen. Such transportation is marked by means of a directed edge from the city of origin to the destination city, as shown in figure 5.7.

Note that the evolution of the epidemic depends strongly on the model definition, and it could be possible that some city becomes infected by a traveling latent individual that develops the disease after arrival in the destination city. If only infectious

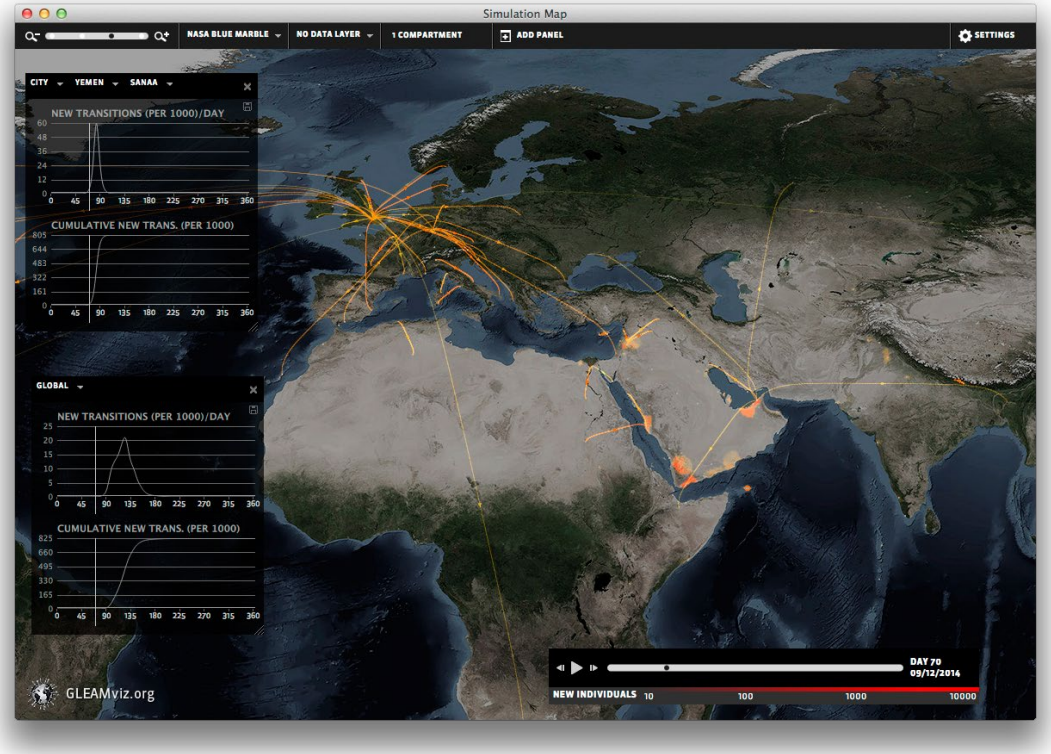

Figure 5.7: Geographic mapping window: single-run simulation with seeding flights

compartments were selected as the current focus compartments, in this case, no seeding flight will be shown.

5.1.4 MAP SETTINGS

Various aspects of the visualization can be controlled through the *Map Settings* menu, which appears at the top right corner of the window, within the *Map Control* shown in figure 5.3. This menu consists of a number of collapsible panels:

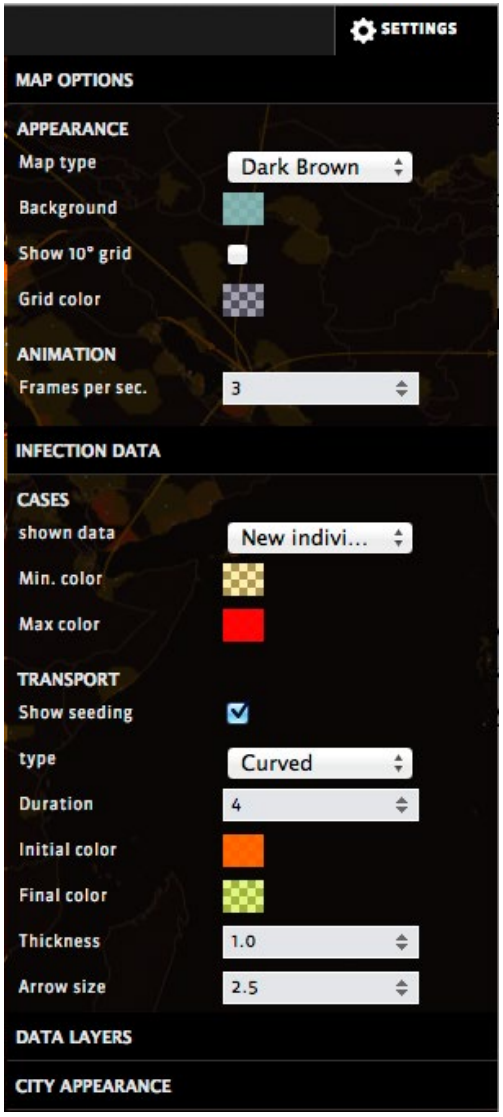

Figure 5.8: Geographic mapping window: Settings

- » Map options
- » Infection data
- » Data layers
- » City appearance

as shown in figure 5.8, allowing the user to customize the map appearance by choosing if and how to display various items (color, size, etc. . .).

5.2 SPATO: SHORTEST PATH TOMOGRAPHY

This visualization is based on the SPaTo Visual Explorer (http://www.spato.net), an interactive software tool for the visualization and exploration of complex networks. By reducing a network (here the transportation network) to the shortest-path tree of a selected root node (here initially the source of the infection), we obtain a local but simpler view of the network that can be easily visualized.

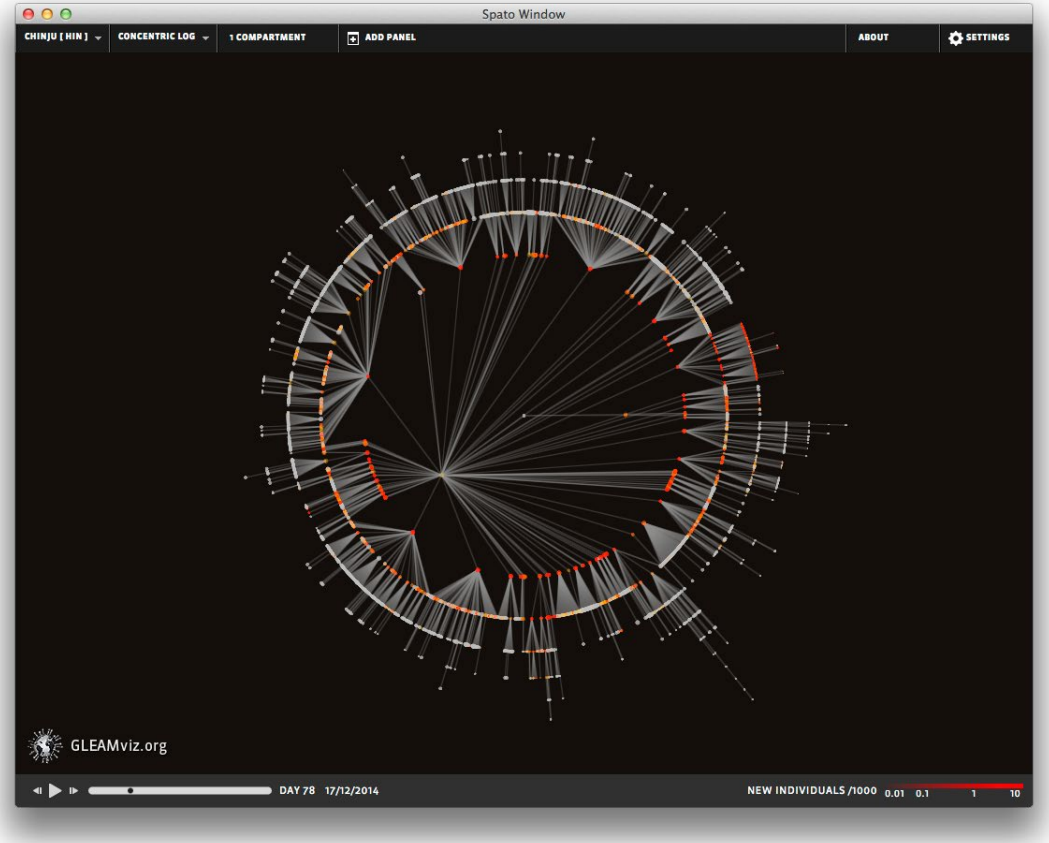

Figure 5.9: SPaTo visualization window: Concentric layout

Figure 5.10: SPaTo visualization window: Geographic layout

This visualization allows the user to switch between a geographic mapping of the transportation hubs (as shown in figure 5.10) and a concentric mapping of the hubs according to the shortest distance (in terms of transportation steps) between the hubs and the root hub (as shown in figure 5.9). In both views, the shortest-path tree among the nodes is rendered by means of edges. The ability to quickly change the root node allows to explore the network from different perspectives. It is possible to select any hub as the root node by clicking on it. It is possible to pan the graph visualization by dragging the mouse pointer, and zoom in/out by using the mouse wheel.

The method and original software were developed by Christian Thiemann in the research group of Dirk Brockmann at Northwestern University and the Max Planck Institute [see www.spato.net].

5.3 3D GLOBE VISUALIZATION

This visualization contains a 3D globe. The rotation of the globe can be manipulated by a mouse, while the zoom level can be adjusted using the mouse wheel. Similar to the 2D map, this visualization shows the number of new cases or cumulative cases as a color coded texture on top of the base texture. For single-run simulations, "seeding" individuals are shown as 3D edges with arrows.

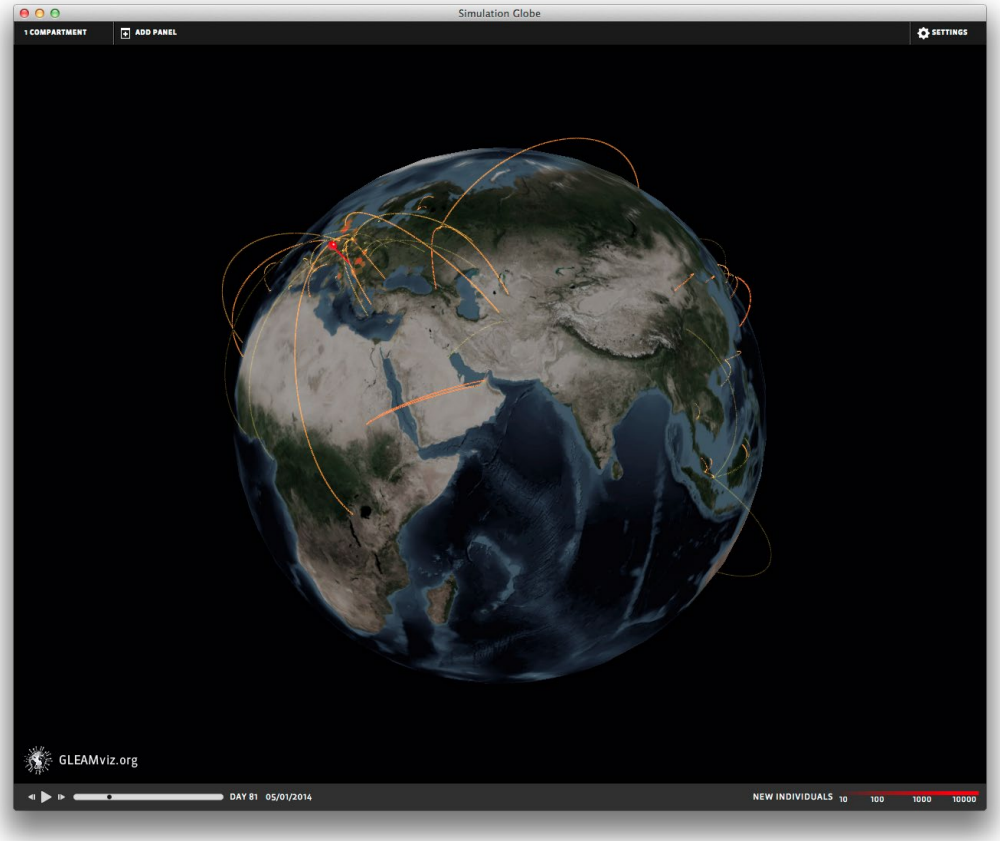

Figure 5.11: Globe visualization

The movie-like play controls allow the user to control the temporal mapping of the evolution of the epidemic spreading. Some visualization options can be configured by means of the settings widget in the top-right corner of the window (background map, coloring, etc.).

5.4 CHARTS PANELS

Charts panels can be visualized in each of the three visualization components.

Each *Charts Panel*, as shown in figure 5.12, contains two charts. The top chart shows the number of new individuals per 1000 in the selected focus compartments for the Charts Panel's context over time. The bottom chart shows the cumulative number of

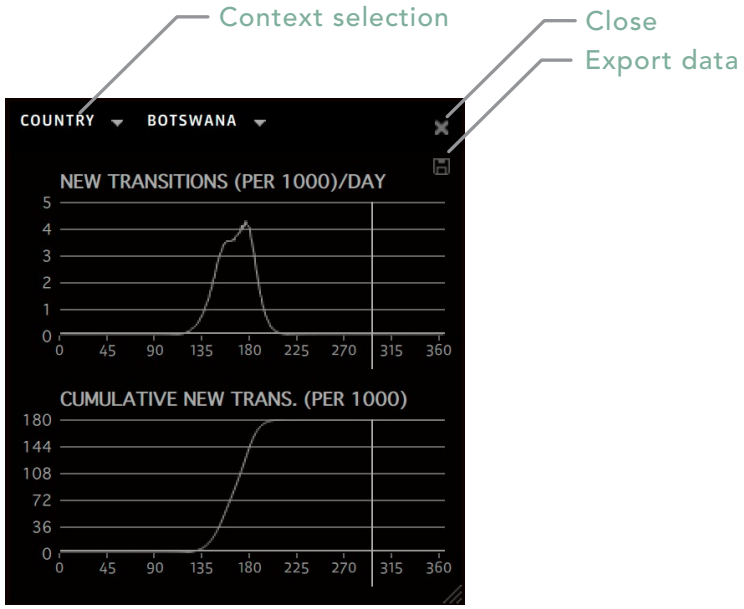

Figure 5.12: Visualization Window: Charts Panel

new individuals per 1000 over time. For multi-run simulations, the median values of the multiple runs and the corresponding 95% confidence intervals are shown.

The *Context selection menu* at the top of each Charts Panel lets the user choose the context for which the corresponding charts show the results data. This context is either: *global*, *hemispheric*, *continental*, *regional*, *by country*, or *by city*.

The vertical line marks the day currently shown on the map. By clicking on the graph, it is also possible to have the visualization map display the state of the epidemic at the corresponding day.

A Charts Panel can be repositioned by dragging the panel's title bar, resized by dragging its bottom-left corner, and closed by clicking the ***Close*** button. Additional Charts Panels can be added by selecting the *Add Panel* widget in the *Map Control*.

The results data shown in a Charts Panel can be exported separately by clicking the ***Export data*** button. The data is exported to a single tab-separated values (TSV) file. There are three columns of data for a single-run simulation and seven for a multi-run simulation. The first column is, in both cases, the *Time-step*, i.e., the day offset since the start of the simulation. For a single-run simulation, the second and third columns contain the number of new individuals per 1000 in the selected focus compartments for the Charts Panel's context and the cumulative number of new individuals, respectively. For a multi-run simulation, the second to seventh columns respectively contain: the median number of new cases; the corresponding lower and upper 95% confidence interval boundary values; the cumulative median; and its lower and upper confidence interval boundary values. The comments at the top of the file contain relevant metadata describing the context and the focus compartments.

06

PREFERENCES WINDOW

The configuration window (shown in figure 6.1) is opened by clicking on the *Preferences* button in the main window menu bar (see section 3.1).

The preferences window allows the user to manually check for software updates and to configure the application behavior (interaction with the GLEAMviz server, simulations' management, visualization and animation settings, etc.)

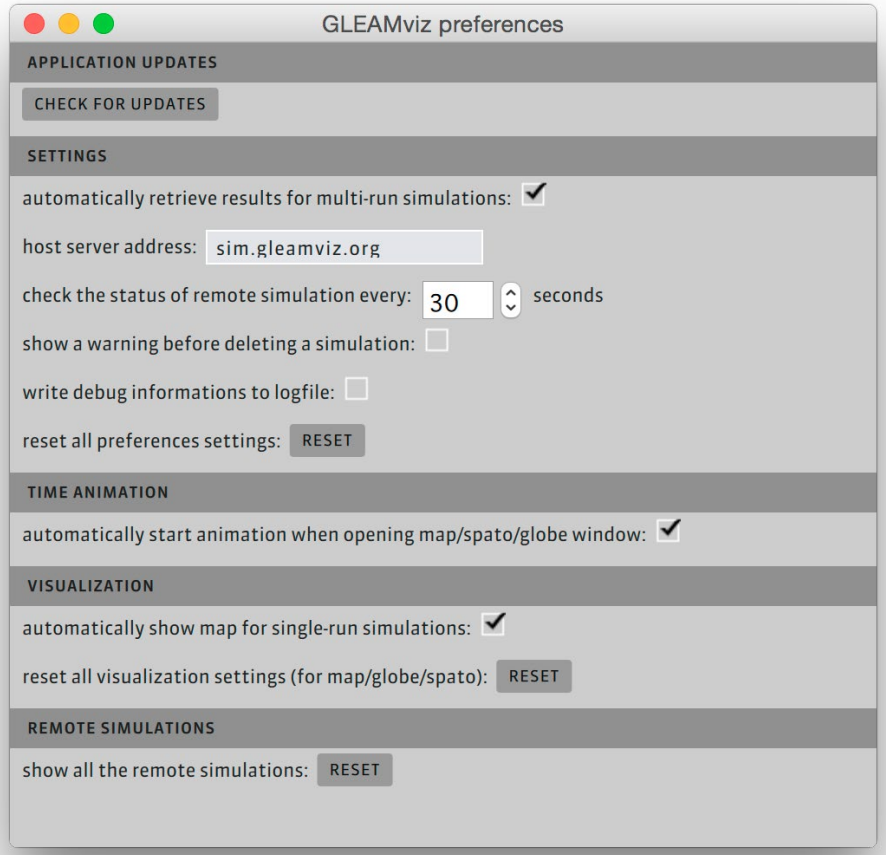

Figure 6.1: Preferences window

07

ALGEBRAIC EXPRESSIONS

Algebraic expressions can be provided for:

1. the values for the variables defined in the compartmental model (see section 4.1.3).
2. the rates of a transition specified in the compartmental model (see section 4.1.2).

A valid algebraic expression consists of numbers, variable references, operators, and parenthesis.

» **Numbers:** The numbers can be integers[1] or decimals and can be written using a scientific notation. Examples of valid numbers are: *123; 1.23; .123; 1e23; 1.23e4; 1.23e+4; 1.23e-4; 1.23E4; 1.23E+4; 1.23E-4.*

» **Variable References:** A variable reference should be a name of another variable defined in the compartmental model. There must be no circular

1 Integer numbers are cast to decimals. The expression 1/2 will thus be properly evaluated as .5.

dependencies among the variables. A *circular dependency* exists when a variable directly or indirectly references itself.

» **Operators:** The allowed operators are: + (addition); - (subtraction); * (multiplication); and / (division). The standard operator precedence applies, from highest to lowest precedence:

1. terms inside parentheses
2. multiplication and division, as they appear left to right
3. addition and subtraction, as they appear left to right

The GLEAMviz client checks to see if expressions are valid and no circular dependencies exist[2] and provides more information on invalid expressions.

2 The GLEAMviz client considers all references independent of the periods in which they are valid when checking for circular dependencies. GLEAMviz could report a circular dependency when in principle there might not be one. Please use intermediate variables in such situations.

08

RESULTS DATA RETRIEVAL

The GLEAMviz Simulator client allows the user to export the results of the simulations that have been successfully completed and retrieved by selecting the *Export results* option in the simulation's drop-down menu. The user is first prompted to select a local directory in which the data will be exported. A new folder will then be created including the following files and sub-directories:

simulation.gvd: the XML simulation definition (including the model specification, the parameters settings, and the initial conditions), which can be used as an import file in the Simulation Builder;

md_cities.tsv: the meta-data for the cities-level aggregated output, mapping the numerical identifiers used for the actual output files;

md_countries.tsv: the meta-data for the countries-level aggregated output, mapping the numerical identifiers used for the actual output files;

md_regions.tsv: the meta-data for the regions-level aggregated output, mapping the numerical identifiers used for the actual output files;

md_continents.tsv: the meta-data for the continents-level aggregated output, mapping the numerical identifiers used for the actual output files;

md_hemispheres.tsv: the meta-data for the hemispheres-level aggregated output, mapping the numerical identifiers used for the actual output files;

cities: a directory containing one *.tsv* output file for each city - result compartment combination, named with the city ID followed by a dash and the index of the focus compartment in the result compartments list as defined in the meta-data files;

countries: a directory containing one *.tsv* output file for each country - result compartment combination, named with the country ID followed by a dash and the index of the result compartment as defined in the meta-data files;

regions: a directory containing one *.tsv* output file for each region - result compartment combination, named with the region ID followed by a dash and the index of the result compartment as defined in the meta-data files;

continents: a directory containing one *.tsv* output file for each continent - result compartment combination, named with the continent ID followed by a dash and the index of the result compartment as defined in the meta-data files;

hemispheres: a directory containing one *.tsv* output file for each hemisphere – result compartment combination, named with the hemisphere ID followed by a dash and the index of the result compartment as defined in the meta-data files;

global: a directory containing one *.tsv* output file for each result compartment, named as "0-" followed by the index of the result compartment as defined in the meta-data files;

seedings.tsv: for single-run simulations only; a file that contains the seeding data (see section 5.1.3). This file contains four columns: the first contains the day offset since the beginning of the simulation, the second and third columns contain the source and target city IDs, the fourth column contains a bit-mask (represented as an integer) in which the n-th lowest bit is 1 if the seeding concerns an individual in the n-th result compartment.

All the *.tsv* files are Tab Separated Values (TSV) files.

The output TSV files contain three columns for single-run simulations and seven for multi-run (MR) simulations. The file columns, listed in order, represent the following quantities:

- the time step, corresponding to the day of the simulation, starting from 0;
- the new number of individuals per 1000;
- the lower bound of the relative 95% confidence interval of the stochastic realization (multi-run only);
- the upper bound of the relative 95% confidence interval of the stochastic realization (multi-run only);
- the cumulative number of individuals per 1000;
- the lower bound of the relative 95% confidence interval of the stochastic realization (multi-run only);
- the upper bound of the relative 95% confidence interval of the stochastic realization (multi-run only).

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2. Wouter Van den Broeck, Corrado Gioannini, Bruno Gonçalves, Marco Quaggiotto, Vittoria Colizza, and Alessandro Vespignani. The gleamviz computational tool, a publicly available software to explore realistic epidemic spreading scenarios at the global scale. *BMC Infectious Diseases,* 11(37), February 2011. 54

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