



# Spark user guide

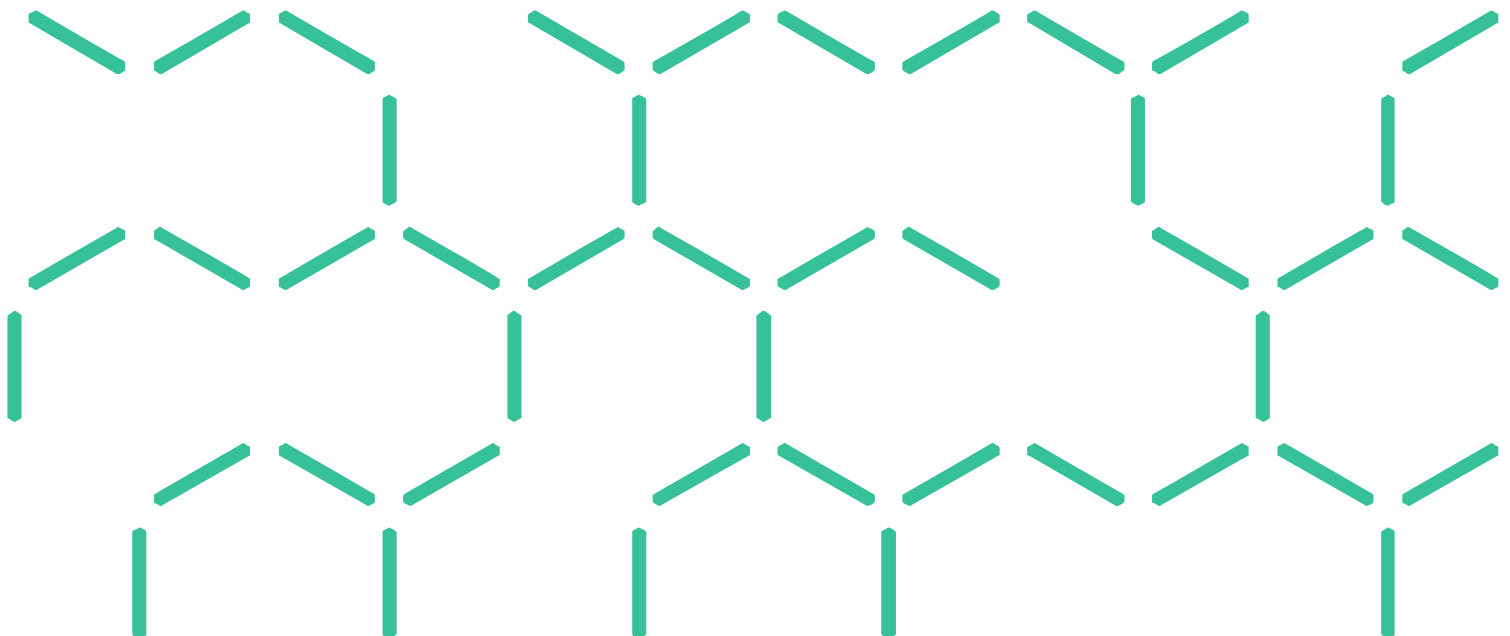
User guide for the Spark software applications

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# 1 Summary

Spark is a toolkit for simulating the spread of wildfires over terrain. The toolkit consists of a number of modules specifically designed for wildfire spread. These include readers and writers for geospatial data, a computational model to simulate a propagating front, a range of visualisations and tools for analysing the resulting data.

This document provides an overview and user guide for a graphical user interface for Spark, '*spark-gui*' and the command-line Spark server application '*spark-batch*'.



## 2 Introduction

Wildfires are dangerous and destructive phenomena frequently occurring in periodically dry regions around the world. The occurrence of fires is a natural process that has shaped landscapes and ecosystems over time. However, increasing urbanisation is bringing more population into contact with wildfires along urban boundaries. The risk to human life and infrastructure has led to intensive research into the prediction of wildfire behaviour. Such predictions are used for risk reduction planning, impact assessment or operational emergency management in the event of a wildfire.



**Figure 1 - Experimental grassfire burn to provide data for new rate-of-spread models.**

The physical process governing fires is very complex, involving interactions over a range of spatial and temporal scales. Despite this complexity, success has been achieved in predicting behaviour using empirical models. These models predict the behaviour of a wildfire using a set of relationships between factors driving the fire (Sullivan 2009b). These factors include weather conditions, such as wind and air temperature, as well as fuel and landscape conditions.

These empirical models can be used to predict rate of spread of a wildfire for a set of given conditions. They are fast to evaluate on a computer making them ideal for providing rapid large-scale predictions for the path of a fire. Alternative computer modelling techniques include fully physical models (Sullivan 2009a), which use a set of interconnected equations governing the underlying dynamics of the fire. These models provide great detail in the physical processes of the fire, but are currently unfeasible to compute at the landscape scale required for operational purposes.

The Spark toolkit is a configurable system for predicting the spread of a fire perimeter over a landscape based on empirical rate-of-spread models. Multiple rate-of-spread models can be employed within the framework representing different fuel types. Different parameters and fuel conditions governing the rate-of-spread can be defined by the user. The system supports standard geospatial data types for fuel layers and meteorological conditions. The predicted results can be written to standard geospatial data types or displayed and viewed within the system.

This user guide covers two particular applications of the Spark toolkit. The first, *spark-gui*, is a fully-featured graphical application allowing the user to read in data layers for fuel and weather, compute a predicted fire perimeter and view the result. The second, *spark-batch*, is a command line tool suitable for running as a server application. This server application could, for example, be used for a predictive ensemble of fire simulations based on different conditions.

## 2.1 Spark and configurability

A key aspect of Spark is configurability. Spark has been designed to handle multiple rate-of-spread models for different fuel types. Spark has also been designed to be compatible with future fire models and new types of fire behaviour.

Instead of pre-set rate-of-spread models, fire behaviour is *programmed* into Spark using a C script. These scripts define the behaviour of the fire in terms of user-defined spatial fuel and meteorological layers. Any valid [OpenCL C code](#) can be used for these scripts, along with a wide range of additional mathematical operations.

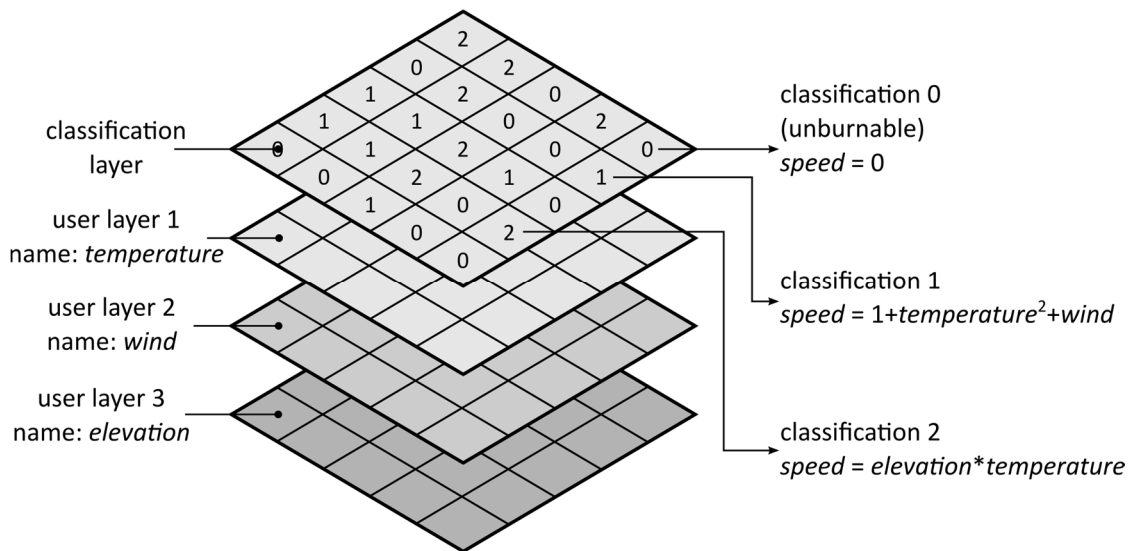


Figure 2 - Schematic of Spark layers

Figure 2 shows a very basic example of Spark configuration. The user has four data layers, shown here vertically stacked for illustration. The top data layer is a fuel or land classification, containing a number representing a fuel type. For example, classification 1 may be grassland and classification 2 may be forest. The classification of zero is reserved as un-burnable. The other data layers are the air temperature, the wind data (this is stored a vector but shown as a single layer for illustration) and the land elevation.

The user also requires two fire behaviour models, one for the grassland areas and one for forest areas. The rate of spread in the grassland (classification 1) is dependent on the temperature and wind (Figure 2, right hand side, middle), whereas the rate of spread for the forest model (classification 2) is dependent on elevation and temperature (Figure 2, right hand side, bottom).

The chosen rates of spread are entered as formulas in text into Spark. The framework takes care of deciding which cell the fire is in, applying the correct rate of spread and updating the fire perimeter accordingly. Spark also takes care of reading and writing geospatial data layers, alignment and projection of the layers and all spatial and temporal aliasing.

The actual scripts for a particular rate of spread can be very complex. We provide a [free source of scripts](#) on our website for the latest fire behaviour models. These can simply be cut and pasted into Spark to provide the desired fire behaviour in different fuel types.

# 3 Spark-gui application

Spark-gui is an implementation of the Spark toolkit behind a graphical user interface. This general-purpose application allows:

- Up to six different types of fuel to be modelled.
- A fire starting condition consisting of a set of points or an ESRI shapefile.
- Either point or gridded input data sets for fuel and weather conditions.
- Output data sets consisting of a raster map of arrival times and a shapefile of isochrones.

Spark applications are run using an XML project file containing fields for controlling and running the simulation. Two XML sample project files with data are included with the spark-gui application.

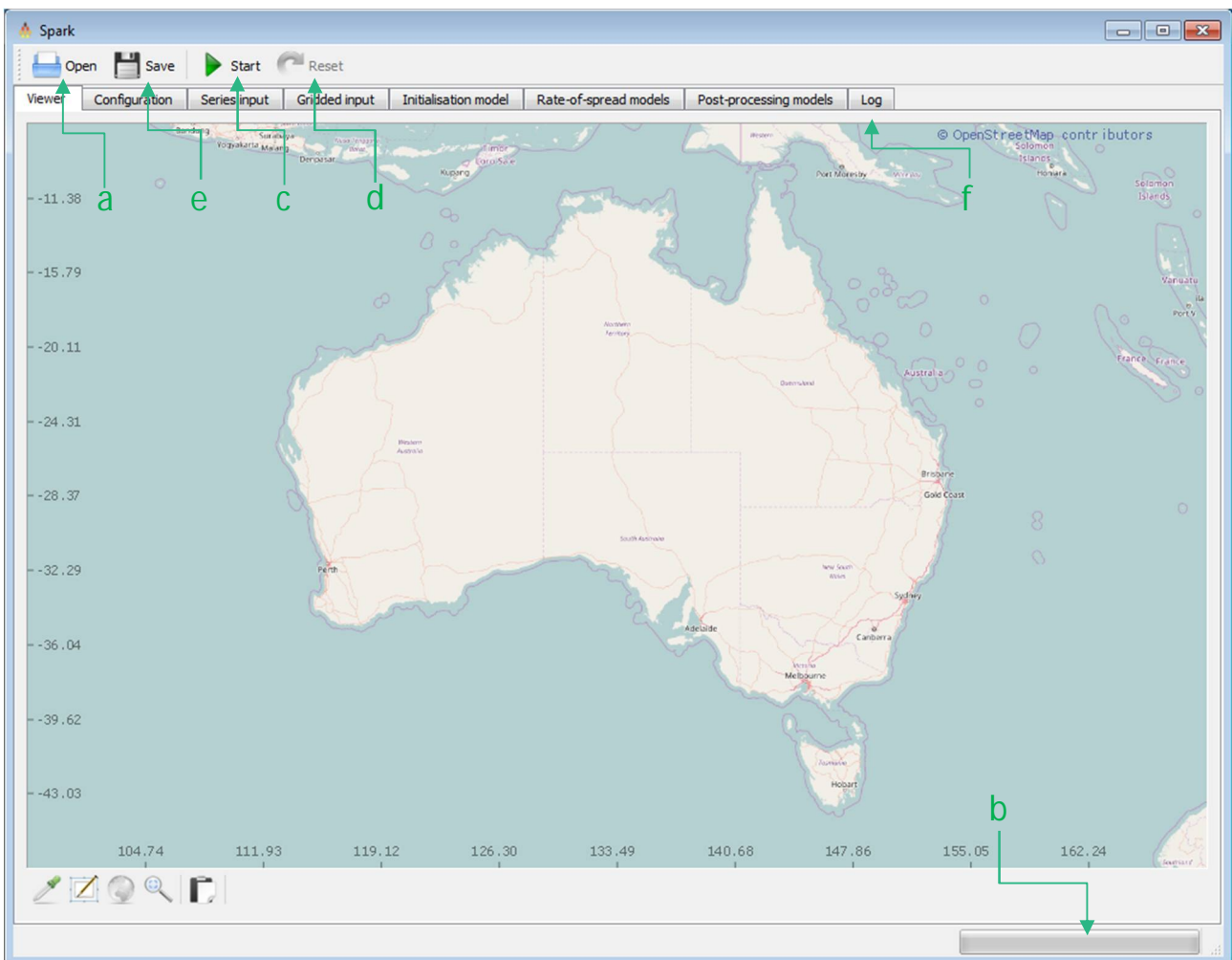


Figure 3 - Spark-gui initial screen.

As an example of the usage of spark-gui we will use the project file *proj1* in the following guide. To open the project, install and run the spark-gui application. The initial screen shows an output map in the viewer window, as shown in Figure 3.



To load a project, click on *Open* (Figure 3, a) and navigate to `/appdata/spark-gui/proj1`. Select and open the `proj1.xml` file. While the project is loading the status bar (Figure 3, b) will be active. When the project has finished loading the status bar will display 'Ready'.

## The application working directory

Spark-gui and spark-batch set the directory containing the xml project file as the current directory, so all filenames can be set relative to the xml project file. Alternatively, a full path can be used.

The project is executed by pressing the *Start* button (Figure 3, c). Execution can be reset at any time by pressing the *Reset* button (Figure 3, d). Any edits to the project (or a new project) can be saved as a XML project file using the *Save* button (Figure 3, e).

When the project is executed the map view will jump to the initial fire location. The simulation should take a few seconds to complete. The default view is a shaded area representing the fire footprint, as shown in Figure 4. Different display layers can be toggled on or off using the named buttons under the map (Figure 4, a).

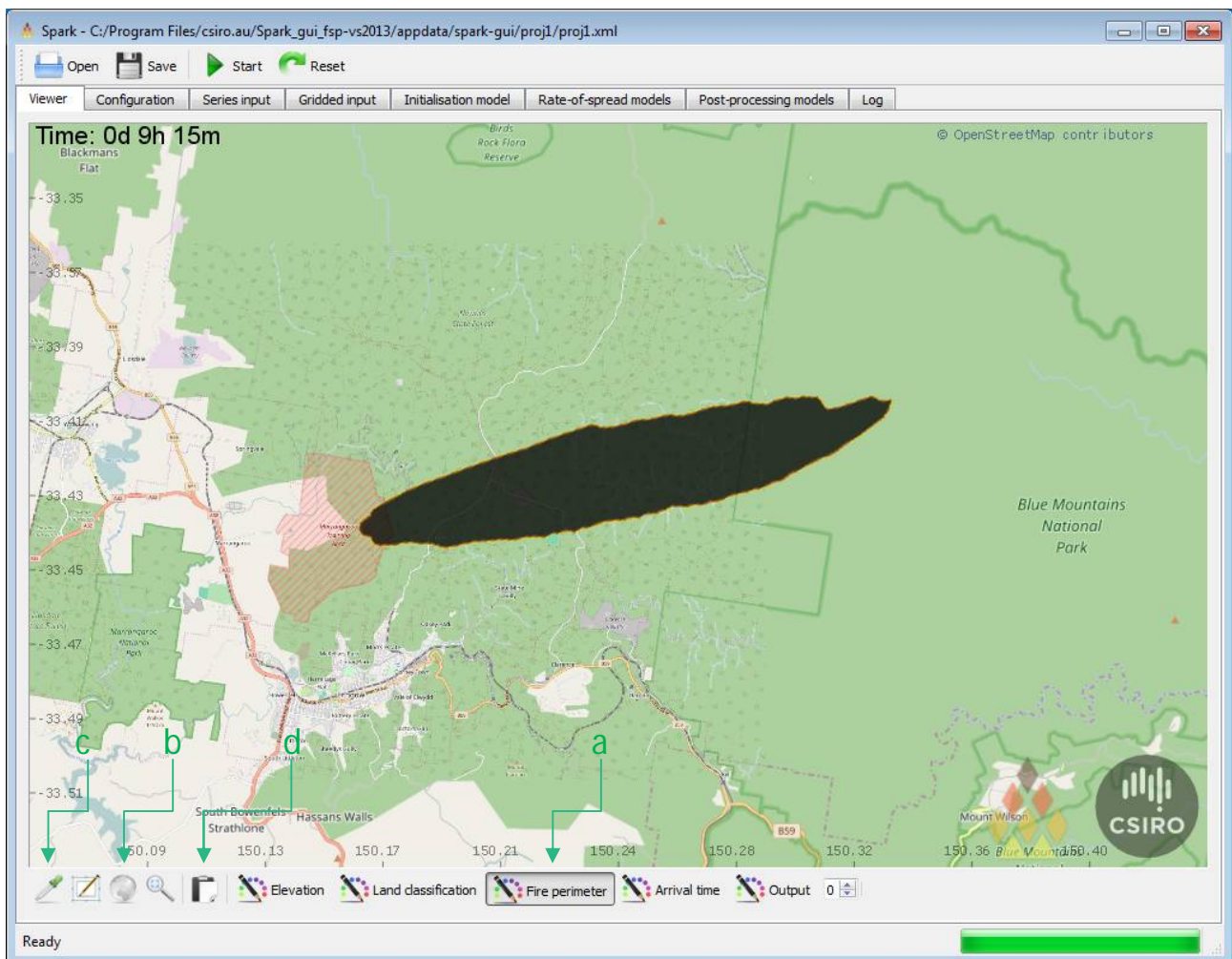


Figure 4 - Spark gui output

To zoom the map to cover the extent of the current layer, use the globe button to the left of the layer controls (Figure 4, b). The current value at the position under the mouse cursor can be displayed for the topmost layer by selecting the eyedropper tool (Figure 4, c). A screenshot of the current map view can be captured using the clipboard tool (Figure 4, d).

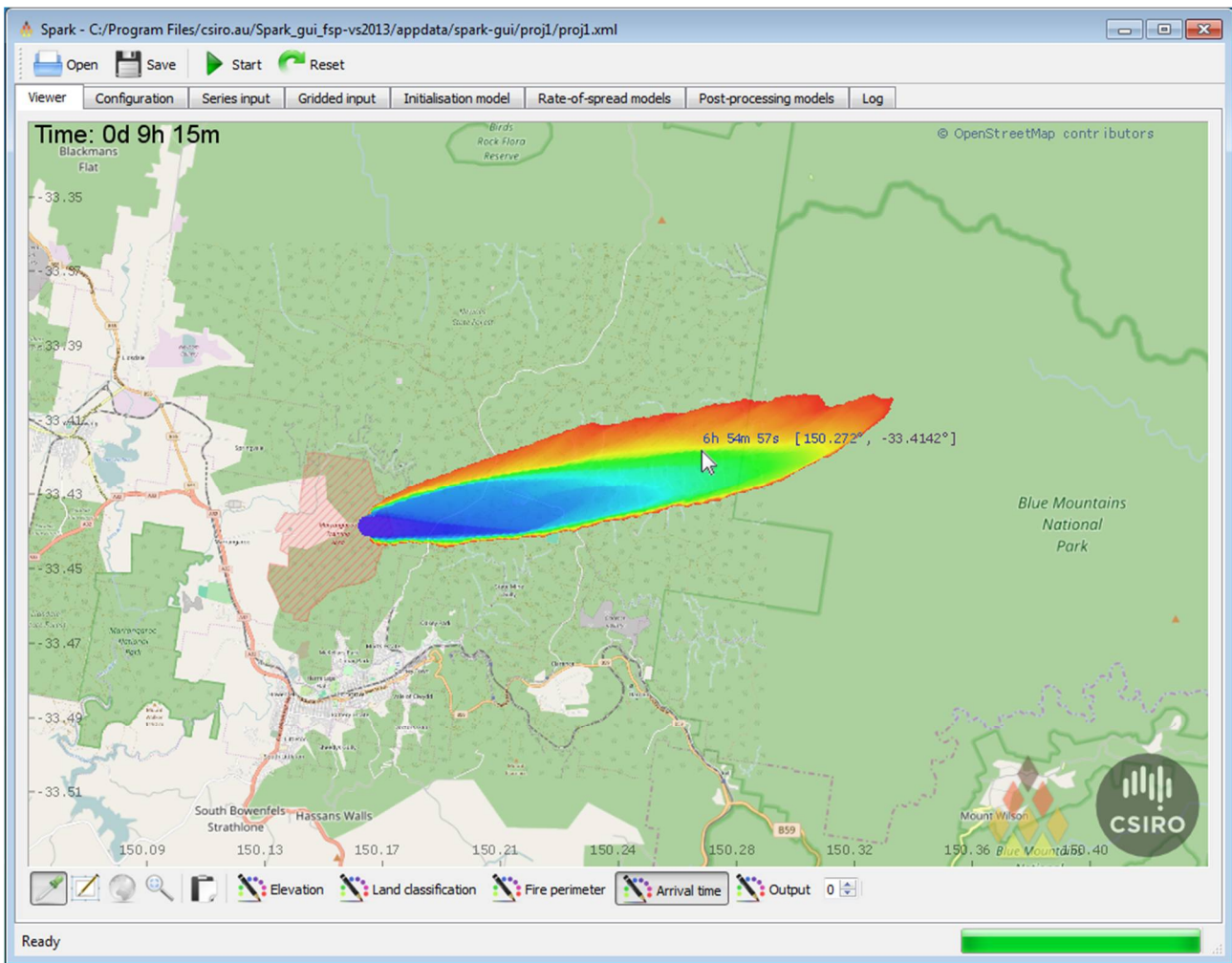


Figure 5 - Spark gui arrival time output

After execution is complete, any output data sets will be written to their required location.

## Errors and warnings

If the status bar displays an error, please refer to the log by selecting the 'Log' tab (Figure 3, f)

## OpenCL

Spark requires OpenCL 1.1 to run. This now comes as standard with all Windows and Mac graphics drivers. Please update your graphics driver before installing Spark to ensure that the latest OpenCL version is installed.

### 3.1 Configuration

After loading the project, the fields within the application will be populated with values defining the simulation. These values include filenames, numbers and scripts. To see the values for *proj1*, select the 'Configuration' tab (Figure 6, a). The configuration screen is shown in Figure 6.

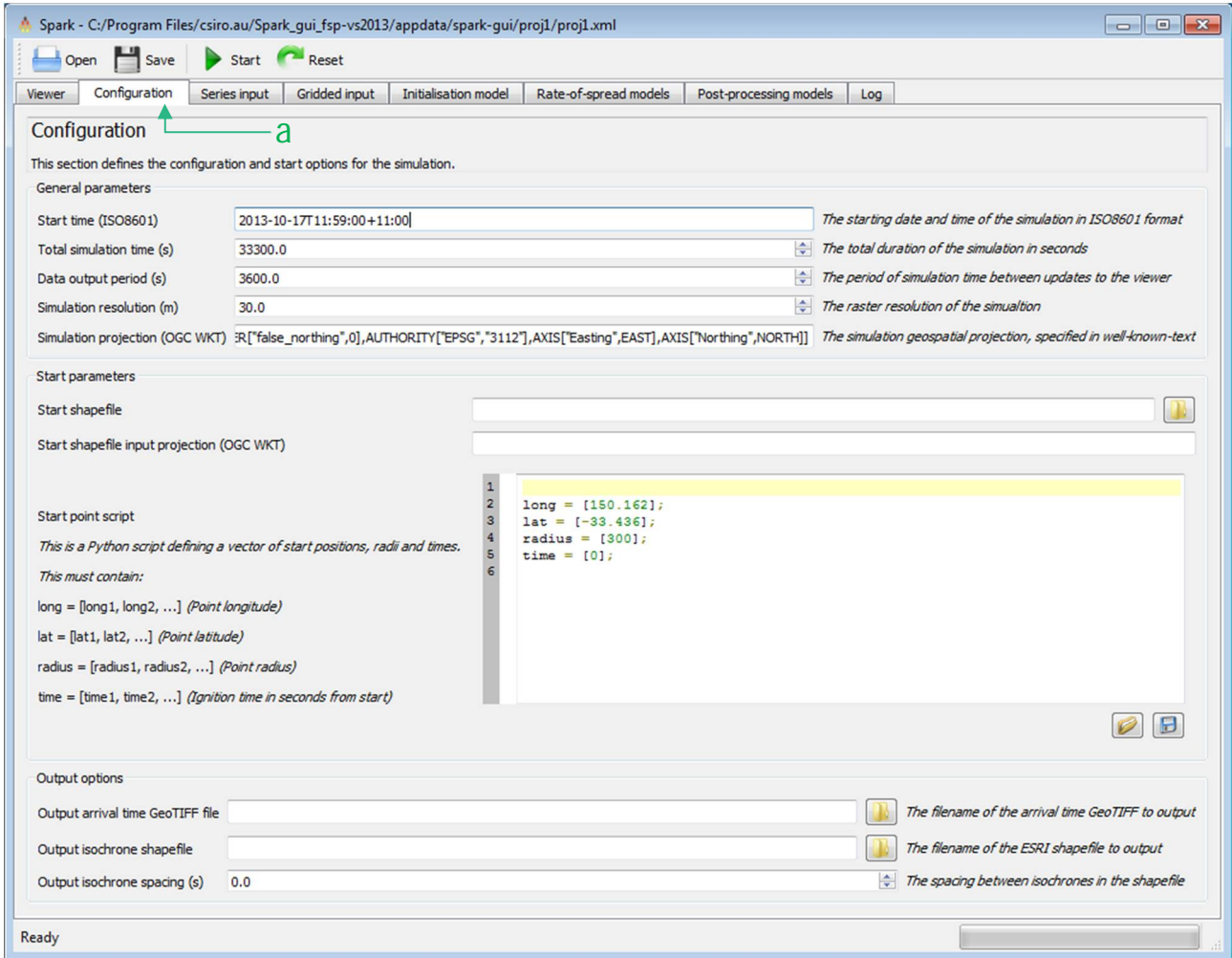


Figure 6 - Spark-gui configuration screen

The configuration tab is divided into several groups, covered in the next sections.

### 3.1.1 General parameters

These fields define the overall parameters for the simulation. All of the parameters must be defined.

NAME	DESCRIPTION	TYPE	XML
<b>Start time (ISO8601)</b>	The start time of the simulation in the <a href="#">ISO8601 format</a> . Here the start time is set to 11:59 am on the 17 <sup>th</sup> October 2013 for the UTC+11 time zone.	Text	<i>Start time</i>
<b>Total simulation time (s)</b>	The length of the simulation in seconds. In this example the simulation runs for 9.25 hours from the start time.	Number	<i>Simulation duration</i>
<b>Data output period (s)</b>	This defines the time period between updates to the map within the Viewer window. This is set to one hour in this example.	Number	<i>Output period</i>
<b>Simulation resolution (m)</b>	The raster resolution of the simulation in meters. All input raster layers are re-sampled to this resolution and all output layers are written at this resolution. Here, the resolution is set to 30 m by 30 m cells.	Number	<i>Simulation resolution</i>
<b>Simulation projection (OGC WKT)</b>	The projection used for the simulation in the <a href="#">Open Geospatial Consortium Well-Know-Text standard</a> . All output raster layers and shapefiles are written using this projection. Here the projection is set to the Australian Lambert projection.	Text	<i>Simulation projection WKT</i>

**Table 1 - Field names for general parameters**

#### Start time

It is recommended that the time zone is specified within the start time input. If this is not specified the simulation will use the local time zone, resulting in different predictions depending on the location the simulation is computed.

#### Simulation projection

The projection used must be a Cartesian co-ordinate system. Mercator or Lambert projections are recommended. For example, the Lambert projection used in *proj1* is a good general-purpose projection for anywhere in Australia.

### 3.1.2 Start parameters

These fields define the starting conditions used for the simulation. A starting condition can either be a shapefile representing an initial fire perimeter or a list of points representing point starting locations. If both are defined, the shapefile will be used preferentially and the starting points will not be used.

NAME	DESCRIPTION	TYPE	XML
<b>Start shapefile</b>	An ESRI shapefile (.shp) defining an initial fire perimeter. No shapefile is used in this example.	Filename	<i>Shape file input source</i>
<b>Start shapefile input projection (OGC WKT)</b>	The shapefile projection in the <a href="#">Open Geospatial Consortium Well-Know-Text standard</a> . No shapefile is used in this example.	Text	<i>Shape file input projection WKT</i>
<b>Start point script</b>	<p>This is a Python script defining the latitude, longitude, radii and start times of each point source. This script must contain the following definitions:</p> <ul style="list-style-type: none"><li>• long (point longitude)</li><li>• lat (point latitude)</li><li>• radius (point radius)</li><li>• time (point activation time)</li></ul> <p>These variables are defined as a Python vector and can be generated in any manner within the script. In this example the start location is simply hard-coded into the script.</p>	Text	<i>Start point script</i>

**Table 2 - Field names for start parameters**

#### Start shapefile

The application currently uses two fields for defining the ESRI shapefile data. These are the shapefile data (.shp) and the projection. The projection is usually stored within a projection (.prj) file, but is not guaranteed to be compatible with the OGC WKT format. To ensure the projection is correctly applied it must be specified in OGC WKT in the shapefile projection field.



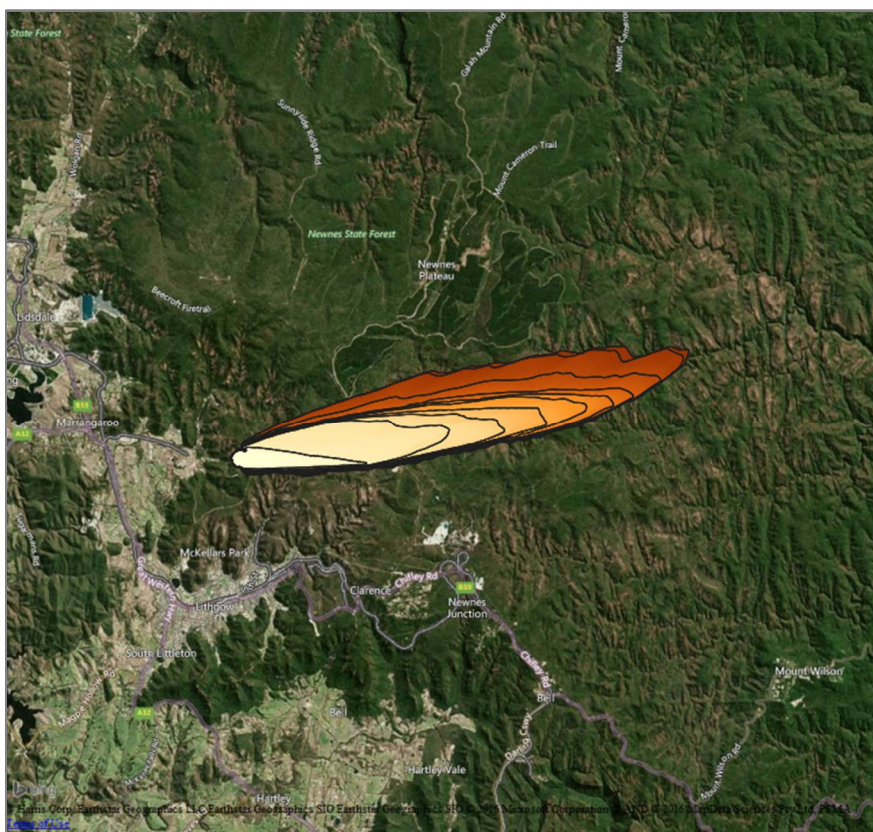
### 3.1.3 Output options

These fields define the simulation output files.

NAME	DESCRIPTION	TYPE	XML
<b>Output arrival time GeoTIFF file</b>	If this field contains a filename a GeoTIFF containing arrival time within the fire perimeter is written to a file with this name. If the field is empty no file is written.	Filename	<i>Output raster file</i>
<b>Output isochrone shapefile</b>	If this field contains a filename an ESRI shapefile of isochrone data is written to a file with this name. The shapefile is written with a projection file containing the simulation projection. If the field is empty no file is written.	Filename	<i>Output shape file</i>
<b>Output isochrone spacing (s)</b>	The spacing in time between the output isochrones in the shapefile.	Number	<i>Output isochrone time</i>

**Table 3 - Field names for output options**

The output files are compatible with all common GIS processing tools, such as QGIS (Figure 7).



**Figure 7 - Output GeoTIFF (shaded by arrival time), and isochrones (black lines)**

## 3.2 Series Input

The applications can use either gridded data sets (spatial raster maps of parameters) or series inputs (a time series representing the change in a particular parameter). The example project *proj1* uses series input for weather conditions, which can be defined and previewed in the 'Series input' tab (Figure 8, a). This window is shown in Figure 8.

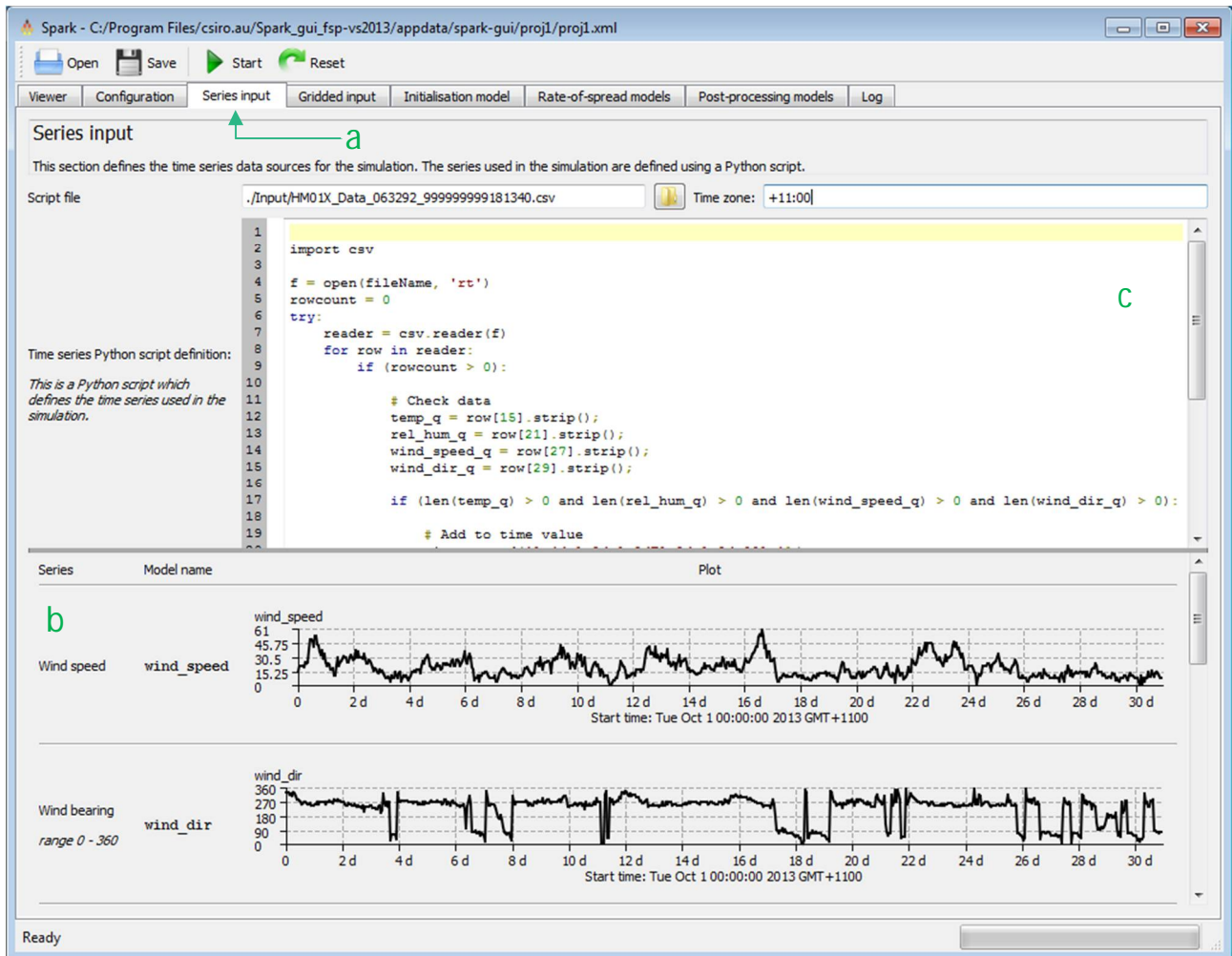


Figure 8 - Spark-gui series input screen

The fields in the series input window are:

NAME	DESCRIPTION	TYPE	XML
Script file	A filename which can be used within the Python script. A variable is created within the Python script called 'fileName' containing the contents of this field.	Filename	Time series source
Time zone	A time zone string which can be used within the Python script. A variable is created within the Python script called 'timeZone' containing the contents of this field.	Text	Time zone
Time series Python script definition	A Python script defining vectors used for time series.	Text	Time series script

Table 4 - Field names for series input

The window is divided into an input Python script in the upper half and a preview of the generated time series in the lower half (Figure 8, b). The spark-gui application pre-defines seven time series, given in Table 5. These time series are populated using the Python script field (Figure 8, c).

NAME	DESCRIPTION
<b>wind_speed</b>	Wind speed.
<b>wind_bearing</b>	Wind bearing in degrees.
<b>temp</b>	Air temperature.
<b>rel_hum</b>	Relative humidity (%).
<b>dew_temp</b>	Dew point temperature.
<b>drought_fac</b>	Drought factor.
<b>curing</b>	Curing parameter.

**Table 5 - Pre-defined time series names for spark-gui**

The Python script, if used, must create vectors containing any or all of the time series names given in Table 5. Additionally, it must create a *time* vector which defines the time values in ISO 8601 format. In the *proj1* example, the Python script uses the Python CSV parser to read a CSV file and append the values within the CSV file to vectors of the temperature, relative humidity, wind speed and wind direction. The script performs an additional check to make sure an entry in the CSV is not blank, and only adds values to the series if data is present.

### Time vector

A '*time*' vector must be defined in the Python script. This currently defines the time values for *all* series [as of v0.8.0].

### Series definitions

If the Python script does not define a series the series will not be created and will not be available in the rate-of-spread models within Spark.

### Units

No units are defined within the framework. The user must take care of unit conversion within rate-of-spread models.



### 3.3 Gridded input

The application can use gridded input layers. Spark supports two or three-dimensional layers (two spatial plus one temporal) and handles all temporal interpolation. Gridded layers are read in using the 'Gridded input' tab (Figure 9, a).

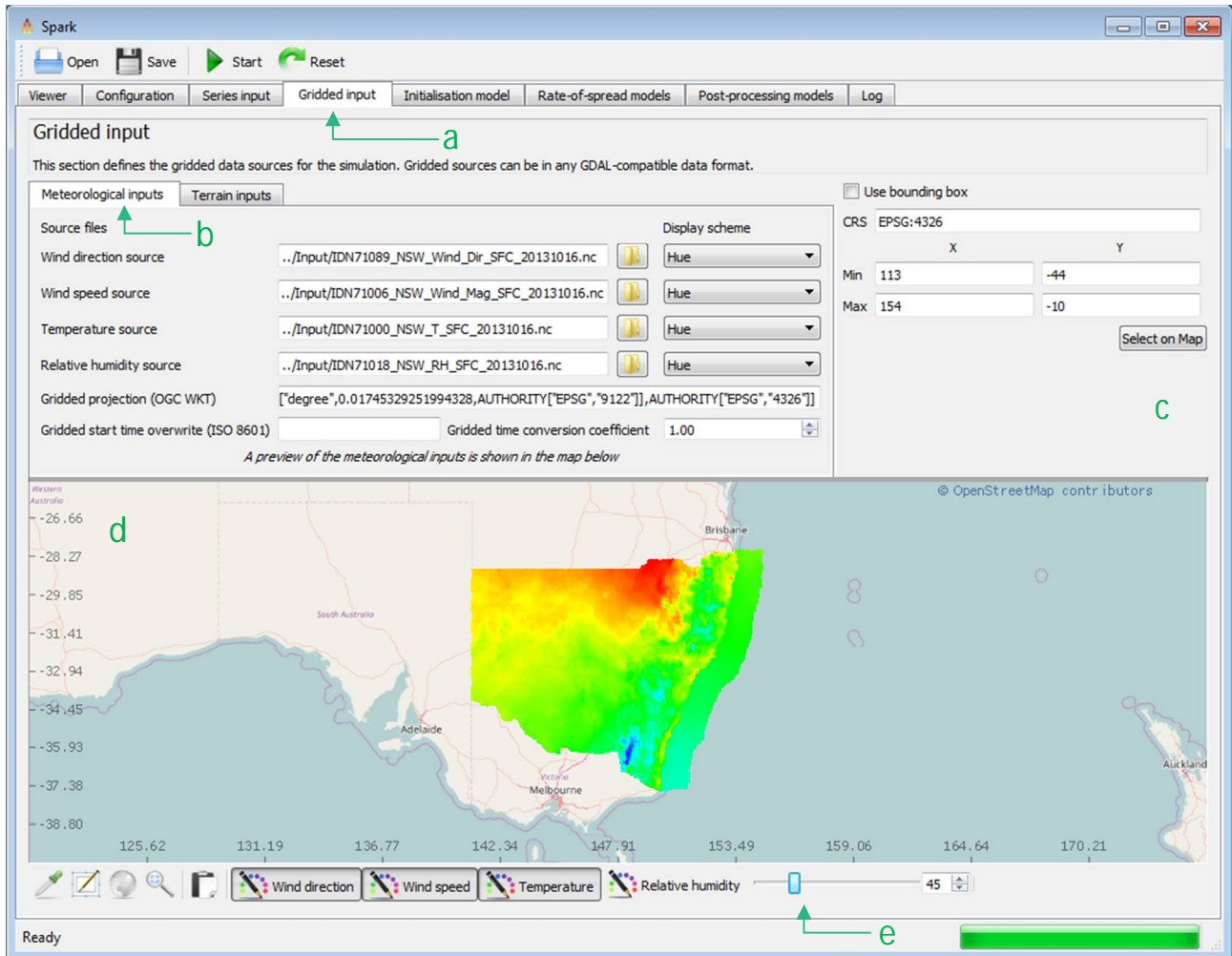


Figure 9 - Spark-gui gridded input screen; meteorological data

Gridded input can be restricted to a sub-region, if required. This can be applied using the bounding box configuration (Figure 9, c), which specifies bounds in longitude and latitude. The bounding box can also be selected on an interactive map using the 'Select on Map' button. To select a region using this tool, hold *shift* and drag on the map to specify the region.

#### Bounding box

A bug in GDAL prevents the bounding box being applied to some GeoTIFF data sets. This will be addressed in a future version [as of v0.8.0].

### 3.3.1 Meteorological inputs

Meteorological input layers are configured in the 'Meteorological inputs' tab (Figure 9, b). The fields in this tab are:

NAME	DESCRIPTION	TYPE	XML
<b>Wind direction source</b>	A raster layer specifying the wind direction in degrees within each cell.	Filename	<i>Gridded wind direction source</i>
<b>Wind speed source</b>	A raster layer specifying the wind speed within each cell.	Filename	<i>Gridded wind magnitude source</i>
<b>Temperature source</b>	A raster layer specifying the air temperature within each cell.	Filename	<i>Gridded temperature source</i>
<b>Relative humidity source</b>	A raster layer specifying the relative humidity (%) within each cell.	Filename	<i>Gridded relative humidity source</i>
<b>Gridded projection (OGC WKT)</b>	The raster layer projection for all meteorological raster layers in the <a href="#">Open Geospatial Consortium Well-Know-Text standard</a> .	Text	<i>Gridded met projection WKT</i>
<b>Gridded start time overwrite (ISO 8601)</b>	An optional start date and time in the <a href="#">ISO8601 format</a> to use instead of the values stored in the meteorological raster layers.	Text	<i>Gridded met start time overwrite</i>
<b>Gridded time conversion coefficient</b>	A multiple to apply to the time-step value for the meteorological raster layers.	Number	<i>Gridded met time conversion coefficient</i>

**Table 6 - Field names for meteorological inputs**

If the input data set is a NetCDF file, the metadata within the file is parsed to generate time information. The parsing process calculates the start time and time step of the input layer. The parsing takes the following steps:

- Search the NetCDF metadata for *time*. If this is not found, stop processing.
- Search the NetCDF metadata for *time#units* and convert to seconds.
- Search for *NETCDF\_DIM\_time\_VALUES*. If this is not found, stop processing.
- Read and convert the *NETCDF\_DIM\_time\_VALUES* array to seconds.
- Check the array for equal time spacing. If the time spacing is unequal, stop processing.
- Calculate the start time of the input layer and the time step.

If the data is not a NetCDF file, or the processing of the metadata fails at any stage, the time step is set to one and the start time is set to zero. In this case, the start time and time step can be manually specified using the *Gridded start time overwrite (ISO 8601)* and *Gridded time conversion coefficient* fields respectively.

Once loaded, the gridded meteorological input data can be previewed on the map below the tab (Figure 9, d). If the input data has a temporal component, the time used for the input layer preview can be changed using the slider below the map (Figure 9, e). Individual layers can be turned on or off using the named buttons on this control.

### 3.3.2 Terrain inputs

Fuel and topographic input layers are configured in the 'Terrain inputs' tab (Figure 10, a). The field values for this tab are given in Table 7.

There are five pre-defined layers within the spark-gui application. These are the fuel classification, a fire history layer, an elevation layer, a fuel load layer and a curing layer. If any of these are empty, the layer is populated with the value in the 'Default value' column. The exception to the default value is the fuel classification layer. If this is empty, the classification of the entire simulation is set to one.

Unlike the meteorological input layers, a different projection system must be specified for each terrain layer. In the *proj1* example the fuel classification layer is in the Albers projection, whereas the elevation is in the WGS84 projection.

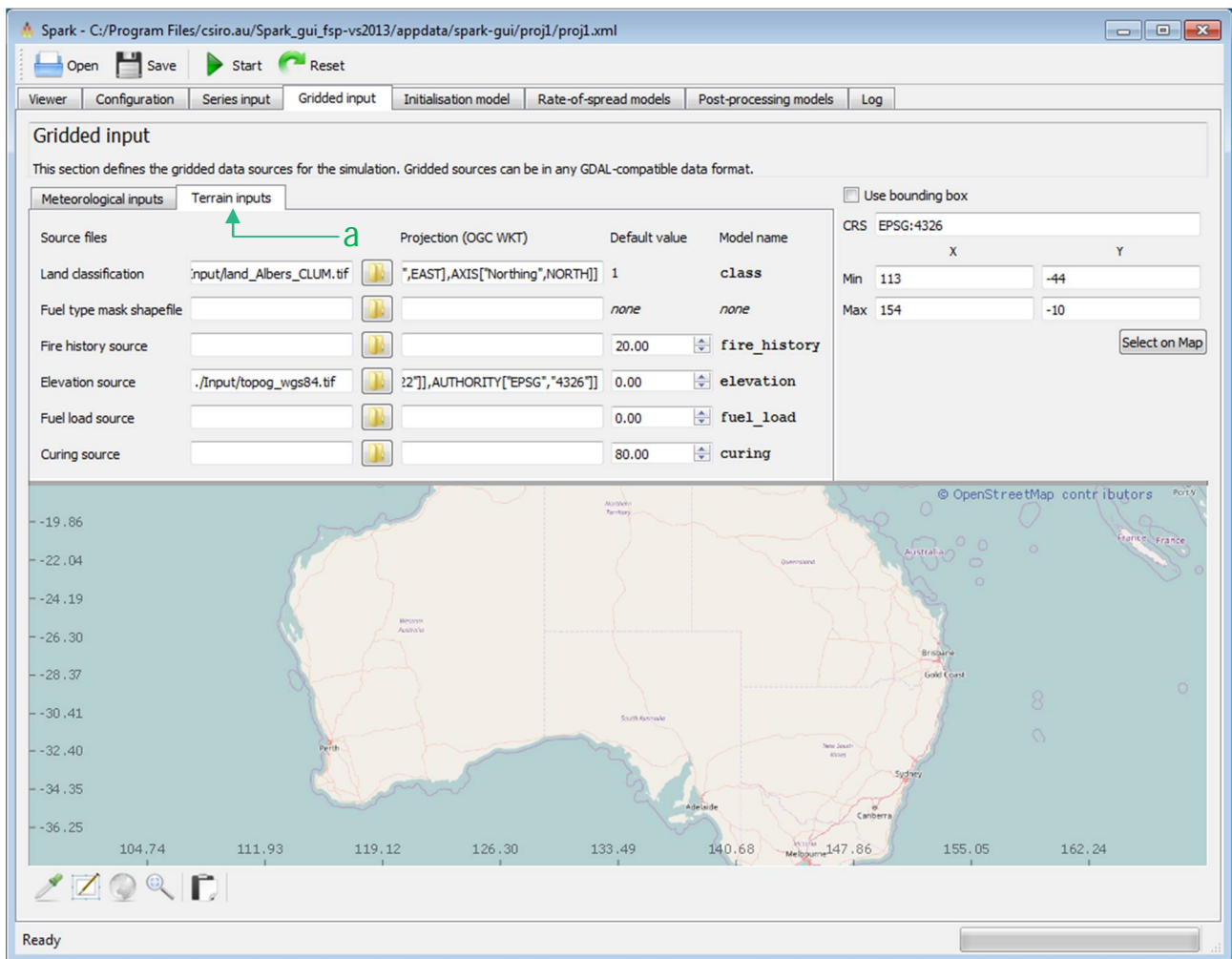


Figure 10 - Spark-gui gridded input screen; terrain data

### Terrain layers

The restriction to five layers is only applicable to the current spark-gui application; the underlying Spark toolkit has no restriction to the number of layers that can be used. New layers will be added in future releases [as of v0.8.0].

NAME	DESCRIPTION	TYPE	XML
<b>Fuel classification</b>	A raster layer specifying the fuel type within each cell.	Filename	<i>Gridded fuel type source</i>
<b>Fuel classification projection</b>	The projection for the fuel classification layer in the <a href="#">OGC WKT standard</a> .	Text	<i>Gridded elevation projection WKT</i>
<b>Fuel type mask shapefile</b>	If a shapefile is specified, any areas within the shapefile are set to a fuel classification of zero (unburnable). This can be used to define a firebreak region, or a previously burnt area.	Filename	<i>Gridded fuel type shape mask source</i>
<b>Fuel type mask shapefile projection</b>	The projection for the fuel classification mask in the <a href="#">OGC WKT standard</a> .	Text	<i>Gridded fuel type shape mask projection WKT</i>
<b>Fire history source</b>	A raster layer defining a fire history value, such as a date or time since last burn.	Filename	<i>Gridded fire history source</i>
<b>Fire history projection</b>	The projection for the fire history layer in the <a href="#">OGC WKT standard</a> .	Text	<i>Gridded fire history projection WKT</i>
<b>Fire history default</b>	The default value for the fire history layer.	Number	<i>Gridded fire history default</i>
<b>Elevation source</b>	A raster layer specifying land elevation with respect to a vertical datum.	Filename	<i>Gridded elevation source</i>
<b>Elevation projection</b>	The projection for the elevation layer in the <a href="#">OGC WKT standard</a> .	Text	<i>Gridded elevation projection WKT</i>
<b>Elevation default</b>	The default value for the elevation layer.	Number	<i>Gridded elevation default</i>
<b>Fuel load source</b>	A raster layer specifying fuel load values.	Filename	<i>Gridded fuel load source</i>
<b>Fuel load projection</b>	The projection for the fuel load layer in the <a href="#">OGC WKT standard</a> .	Text	<i>Gridded fuel load projection WKT</i>
<b>Fuel load default</b>	The default value for the fuel load layer.	Number	<i>Gridded fuel load default</i>
<b>Curing source</b>	A raster layer specifying curing values.	Filename	<i>Gridded curing source</i>
<b>Curing projection</b>	The projection for the curing layer in the <a href="#">OGC WKT standard</a> .	Text	<i>Gridded curing projection WKT</i>
<b>Curing default</b>	The default value for the curing layer.	Number	<i>Gridded curing default</i>

**Table 7 - Field names for terrain inputs**

Each of the layers can be referred to in the initialisation, post-processing and rate-of-spread models by the name given in the '*Model name*' column. In addition, the following layers are defined and can be used:

NAME	DESCRIPTION
<b>speed_reduce</b>	Speed reduction layer
<b>FHSs</b>	Surface fuel hazard score.
<b>FHSns</b>	Near-surface fuel hazard score
<b>Hns</b>	Near surface fuel height.
<b>H</b>	Fuel height.

**Table 8 - Additional terrain layers defined within the Spark applications**

### 3.4 Initialisation model

The initialisation model is a powerful pre-processing step run over all data layers after they are created, and used in the simulation. The use of an initialisation model is entirely optional, but allows for manipulation and population of the data layers. The model allows values in the data layers to be re-written or populated according to any user-defined function. The final initialisation script must be in [OpenCL C code](#).

The processing in *proj1* shows a typical use of an initialisation model. The raw data layer for the classification uses a three digit Australia land use classification code (*ALUM*). This three-digit code must be converted into the four classifications used within this example: un-burnable (0), grassland (1), forest (2) and urban (3). For example, the first step converts any *ALUM* code starting with '6' into an un-burnable region, as codes starting with '6' are water regions.

The second step of the processing carries out a different processing function. In this step, the layers *FHSs*, *FHSns* and *Hns* for the dry eucalypt model are populated within each cell using an exponential growth curve based on the fuel age layer.

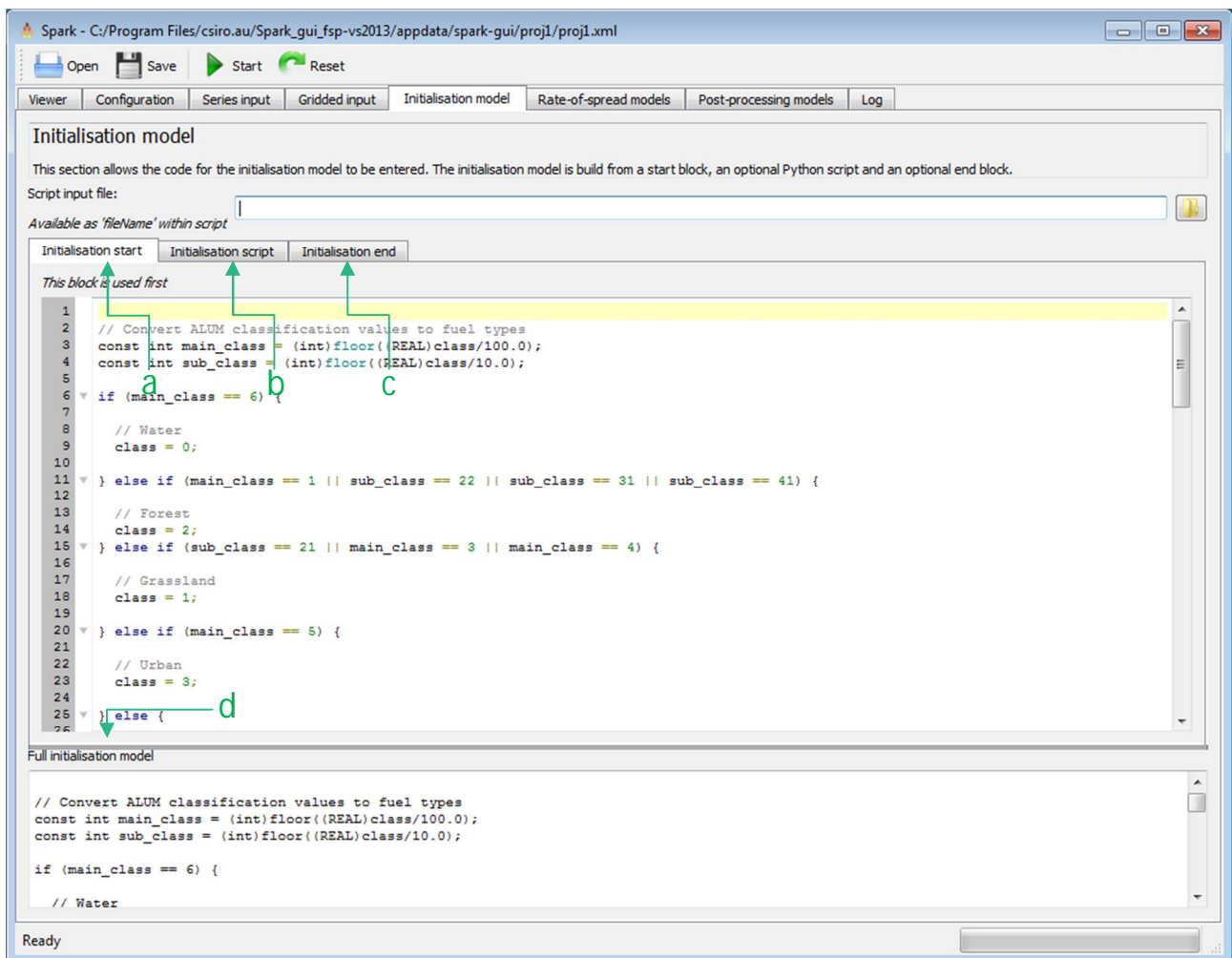


Figure 11 - Spark-gui initialisation model

The initialisation model can be used to carry out any such processing of this type. For flexibility the model is split within the Spark applications into three steps. The full model script is built up from three blocks: a starting script (Figure 11, a), a script generated by Python (Figure 11, b) and an

ending script (Figure 11, c). For reference the entire initialisation script is shown in a display at the bottom of the tab (Figure 11, d). This structure allows, for example, a Python script to automatically generate mappings between multiple fuel types and the fuel types used within the application.

The fields in this tab are:

NAME	DESCRIPTION	TYPE	XML
<b>Script input file</b>	A filename which can be used within the Python script. A variable is created within the Python script called 'fileName' containing the contents of this field.	Filename	<i>Initialisation Python input file</i>
<b>Initialisation start</b>	A script specifying the starting block of the initialisation model.	Text	<i>Initialisation start string</i>
<b>Initialisation script</b>	A Python script defining a generated block of text to append to the initialisation model. The text must be added to a string named 'initString' within the Python script.	Text	<i>Initialisation Python script</i>
<b>Initialisation end</b>	A script appended to the end of the start block and the generated Python script.	Text	<i>Initialisation end string</i>

**Table 9 - Field names for initialisation model**

## Initialisation and optimisation

For optimisation it is best to put as much calculation as possible within the initialisation model, rather than the rate-of-spread models.



## 3.5 Rate-of-spread models

The rate-of-spread models are the core of the Spark application. These define the local rate of spread of a fire perimeter based on an empirical relationship. For the example *proj1* three rates-of-spread are defined: the CSIRO grasslands model, the Dry Eucalypt model and a placeholder urban model. The rate-of-spread model scripts must be in [OpenCL C code](#).

There are six input tabs within this window corresponding to fuel classifications 1-6. The rate-of-spread model in the 'Class 1' tab is used to calculate the rate of spread within any cells with a fuel classification value of 1, the rate-of-spread model in the 'Class 2' tab is used to calculate the rate of spread within any cells with a fuel classification value of 2, and so on.

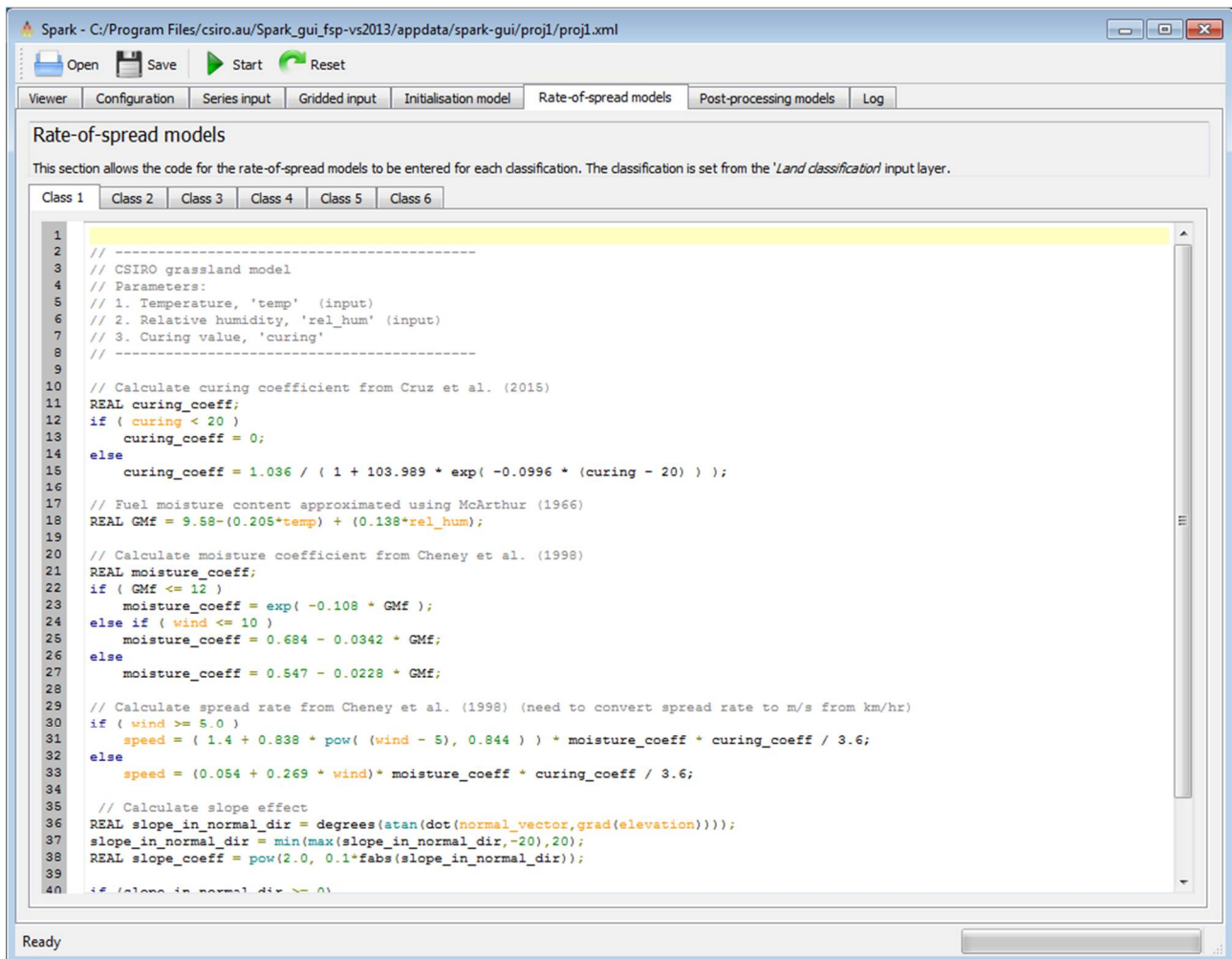


Figure 12 - Spark-gui rate-of-spread models

The grassland and dry eucalypt models are complex models containing a large amount of code. A much simpler example illustrating the rate of spread scripts is the urban rate of spread model in the *Class 3* tab. This rate-of-spread model is given by:

```
speed = (REAL)0.01*wind;
```

All rate-of-spread models must contain a `speed =` definition. This defines the outward speed of the fire perimeter. Sets of isochrones for three different speed definitions are shown in Figure 13.

In each case the initial fire is a circle of diameter 20 meters, shown as the inner isochrone at zero time. Isochrones are shown at 25 second intervals.

- In the first case (Figure 13, a) the speed definition is  $\text{speed} = 1$ . The initial circular perimeter spreads with a radial speed of 1 m/s in all directions, ending as a circle of diameter 220 meters.
- The second case (Figure 13, b) uses the wind vector defined in the simulation. The wind vector in these examples is in the vertical direction with respect to the figure, from the bottom to the top, with magnitude 1 m/s. The speed definition here is  $\text{speed} = 1 + \text{wind}$ , where  $\text{wind}$  is specially defined quantity<sup>1</sup> representing the component of the wind in the direction of the fire front. In this case the fire grows outwards at a rate of 1 m/s and moves forward at an additional rate of 1 m/s, resulting in a stretched obround fire perimeter.
- The final example (Figure 13, c) is an example of a non-linear rate of spread. The speed definition here is  $\text{speed} = 1 + \text{wind}^2$ , resulting in a pointed fire perimeter.

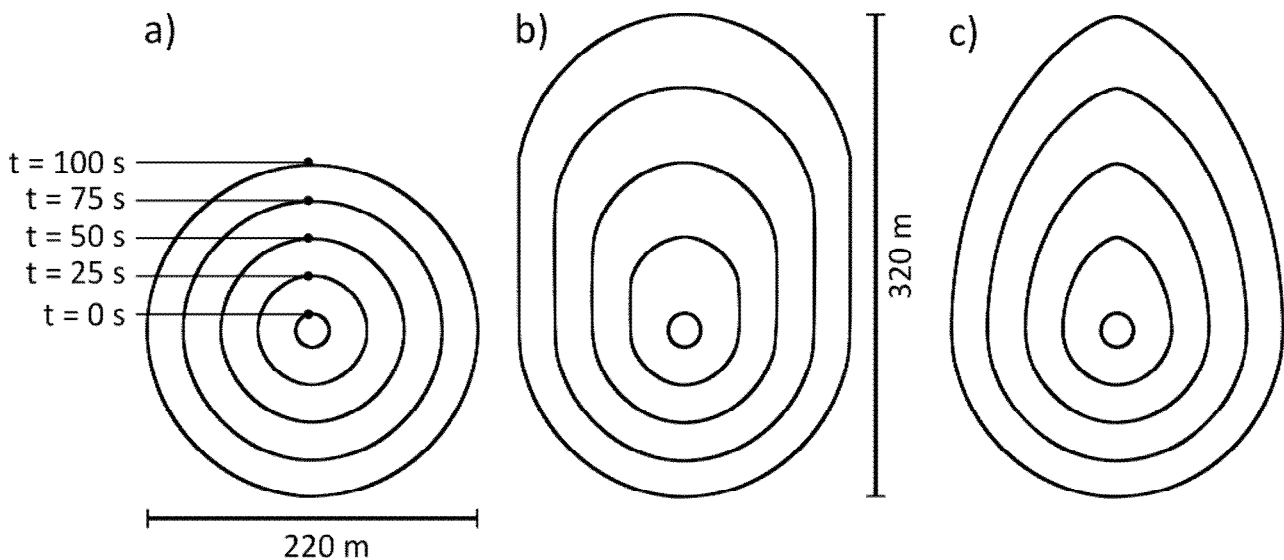


Figure 13 - Speed definition examples

In the case of the urban model, the fire perimeter is simply moved in the direction of the wind at 1% of the wind speed.

The other two models in the example use a much more complex relationship for the rate of spread which is coupled with factors such as fuel moisture and the topography of the terrain. For example, the CSIRO grasslands model calculates the rate-of-spread in a number of steps.

- Firstly, the curing coefficient used in the model is calculated using an empirical formula given by Cruz 2015. The  $\text{curing}$  variable corresponds to the value defined either in the

<sup>1</sup> Mathematically the variable  $\text{wind}$  is defined as  $\text{wind} = \max(\hat{\mathbf{n}} \cdot \mathbf{w}, 0)$ , where  $\mathbf{w}$  is the wind vector and  $\hat{\mathbf{n}}$  is the normal vector to the fire perimeter.



terrain input layer, or the curing time-series. Note that local variables, such as `curing_coeff`, can be defined and used in the script.

```
// Calculate curing coefficient from Cruz et al. (2015)
REAL curing_coeff;
if (curing < 20)
    curing_coeff = 0;
else
    curing_coeff = 1.036/(1+103.989*exp(-0.0996*(curing-20)));
```

- Next, the grassland fuel moisture is calculated using a relationship given by McArthur 1966, based on the local temperature, `temp`, and relative humidity, `rel_hum`. These two layers correspond to

```
// Fuel moisture content approximated using McArthur (1966)
REAL GMf = 9.58-(0.205*temp) + (0.138*rel_hum);
```

- The fuel moisture is used to calculate the grassland moisture coefficient:

```
// Calculate moisture coefficient from Cheney et al. (1998)
REAL moisture_coeff;
if (GMf <= 12)
    moisture_coeff = exp(-0.108*GMf);
else if ( wind <= 10 )
    moisture_coeff = 0.684-0.0342*GMf;
else
    moisture_coeff = 0.547-0.0228*GMf;
```

- Finally, the speed is calculated using the CSIRO grassland model (Cheney 1998). Note the spread rate is converted to  $\text{m s}^{-1}$  from  $\text{km hr}^{-1}$ :

```
// Calculate spread rate from Cheney et al. (1998)
if ( wind >= 5.0 )
    speed = (1.4+0.838*pow((wind-5),0.844))*moisture_coeff*curing_coeff/3.6;
else
    speed = (0.054+0.269*wind)*moisture_coeff*curing_coeff/3.6;
```

- The model then applies the Kataburn (Sullivan 2014) slope correction:

```
// Calculate slope effect
REAL slope_in_normal_dir =
degrees(atan(dot(normal_vector,grad(elevation))));
slope_in_normal_dir = min(max(slope_in_normal_dir,-20),20);
REAL slope_coeff = pow(2.0, 0.1*fabs(slope_in_normal_dir));

if (slope_in_normal_dir >= 0)
    speed *= slope_coeff;
else
    speed *= slope_coeff/(2*slope_coeff-1.0);
```

Similar processing is carried out for the Dry Eucalypt model to calculate the rate of spread.

## 3.6 Log

The log provides output and information on the simulation. On start-up similar text to that shown in Figure 14 should appear.

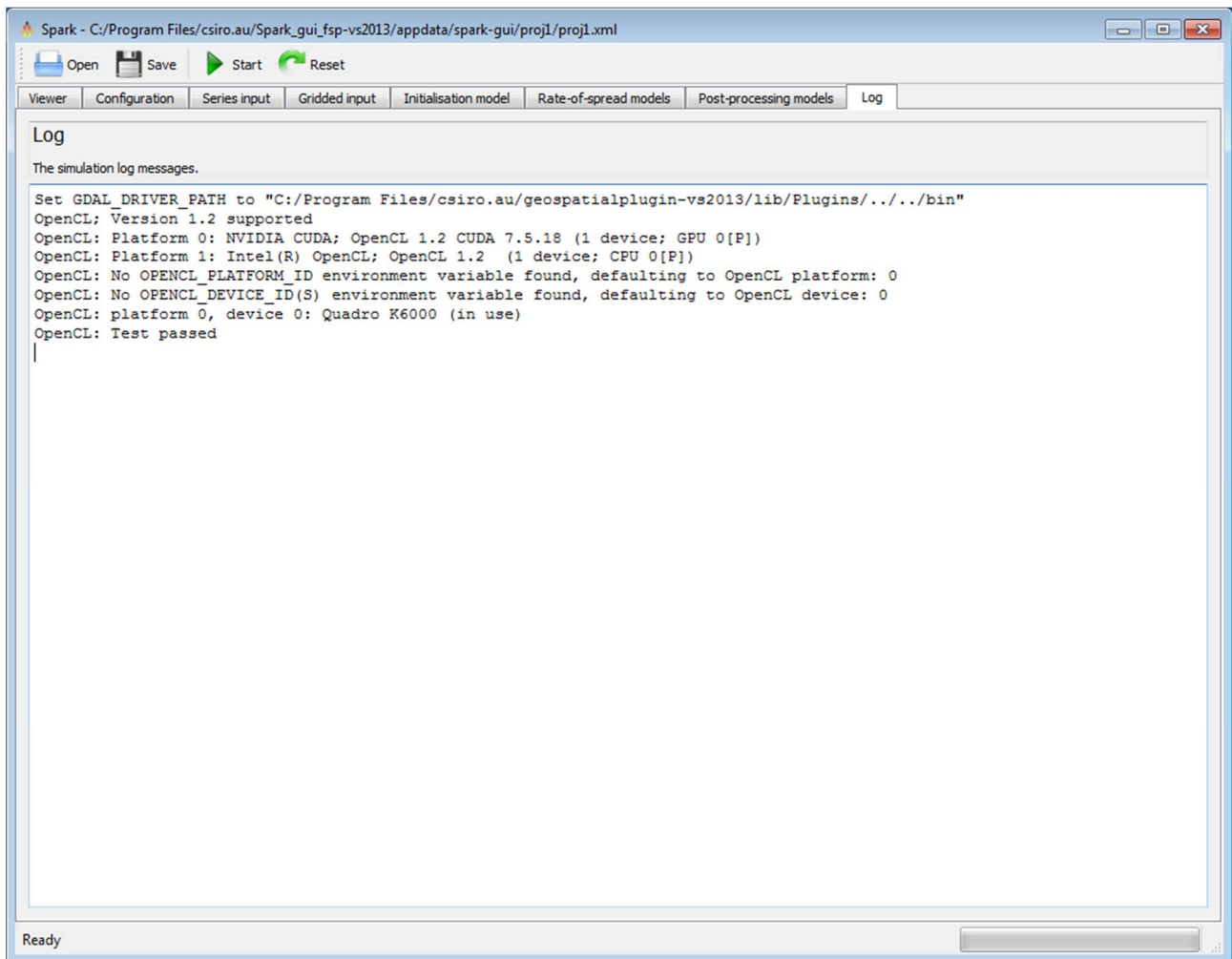


Figure 14 - Spark-gui simulation log

Any errors are highlighted in red with a description of the error encountered.

## 4 Spark-batch application

The *spark-batch* package is a stand-alone command-line application. The application is configured to be deployed to multi-CPU or GPU servers. The input to the application is an XML project file for the configuration of the solver and a series of input data sets. XML project files created using the *spark-gui* application are compatible with *spark-batch*.

The application must be run in a project directory containing the XML project file. This XML file is supplied to the application as a command line argument, for example, if the input XML file is *proj1.xml* the application is executed using the command:

```
spark-batch ./proj1.xml
```

Outputs will be written to the files defined within the XML file. The batch application also contains a test to ensure the application is working correctly. To carry out the test, execute the command:

```
spark-batch --test
```

If all is working correctly, an image called *spark-batch\_test\_result.png* will be written to the current directory. The image is shown in Figure 15.

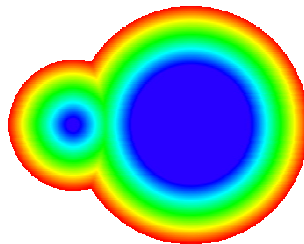


Figure 15 - spark-batch test result

The XML project file can either be generated using the *spark-gui* application or automatically created. The XML must be contained by an `<operation>` tag. The fields within the file have the following form:

```
<input globalname="Start time">2013-10-17T11:59:00+11:00</input>
```

The `globalname` tag for each of the inputs is given under the 'XML' column in each of the tables in the *spark-gui* section.

### XML composition

XML contains escape characters, for example the less than sign '`<`' is encoded using the string '`&lt;`'. Care must be taken to use these escape characters when manually writing code in XML.

# Appendix

Spark contains a number of internally defined variables which provide access to information required for fire modelling. These are given in Table 10, with the availability of the variable shown in the last column.

VARIABLE	TYPE	DESCRIPTION	AVAILABILITY*
<b>easting</b>	scalar	The cell easting value (m).	I
<b>northing</b>	scalar	The cell northing value (m).	I
<b>speed</b>	scalar	Required: sets the normal speed at the perimeter (m/s).	RP
<b>wind</b>	scalar	The dot product of the wind and front normal, limited by zero.	R
<b>wind_vector</b>	vector	The wind vector.	R
<b>normal_vector</b>	vector	The normal vector of the perimeter.	R
<b>class</b>	scalar	The fuel classification value.	IRP
<b>random</b>	scalar	A random number from a uniform distribution between 0-1.	IRP
<b>output0</b>	scalar	Internal user-defined data layer, written to 'output grid' layer 0.	IRP
<b>output1</b>	scalar	Internal user-defined data layer, written to 'output grid' layer 1.	IRP
<b>output2</b>	scalar	Internal user-defined data layer, written to 'output grid' layer 2.	IRP
<b>arrival</b>	scalar	The ignition (arrival) time of the perimeter at the cell (s). No-data values indicate no recorded arrival time.	P
<b>hour</b>	scalar	The current hour in simulation time.	R
<b>time</b>	scalar	The current solver time (s).	RP
<b>layername</b>	scalar	The interpolated value within the cell from the user-defined layer or time series named <i>layername</i> .	IRP
<b>dx(layername)</b>	scalar	The x-spatial derivative of the user-defined layer named <i>layername</i> .	IR
<b>dy(layername)</b>	scalar	The y-spatial derivative of the user-defined layer named <i>layername</i> .	IR
<b>grad(layername)</b>	vector	The gradient of the user-defined layer named <i>layername</i> .	IR

**Table 10 - Internal variables used in Spark models.**

**\* I: Initialization models, R: Rate-of spread models, P: Post-processing models**

# References

Cheney NP, 1998, Prediction of fire spread in grasslands. *International Journal of Wildland Fire* 8, 1-15.

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McArthur AG, 1966, Weather and grassland fire behaviour. Commonwealth Department of National Development. Forestry and Timber Bureau, Leaflet 100, Canberra, ACT. 23 pp.

Sullivan AL, 2009a, Wildland surface fire spread modelling, 1990–2007. 1: Physical and quasi-physical models, *International Journal of Wildland Fire*, 18, 349–368

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