The Australian Society
for Operations Research

Fire simulations, risk analytics and optimisation

Simon Dunstall, CSIRO Data61

Australia's National Science Agency

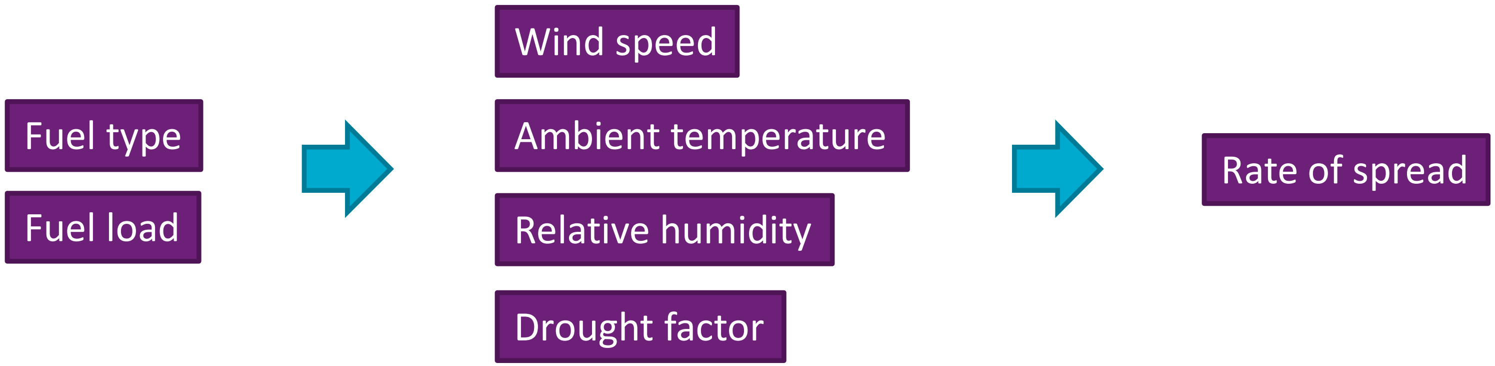
CSIRO

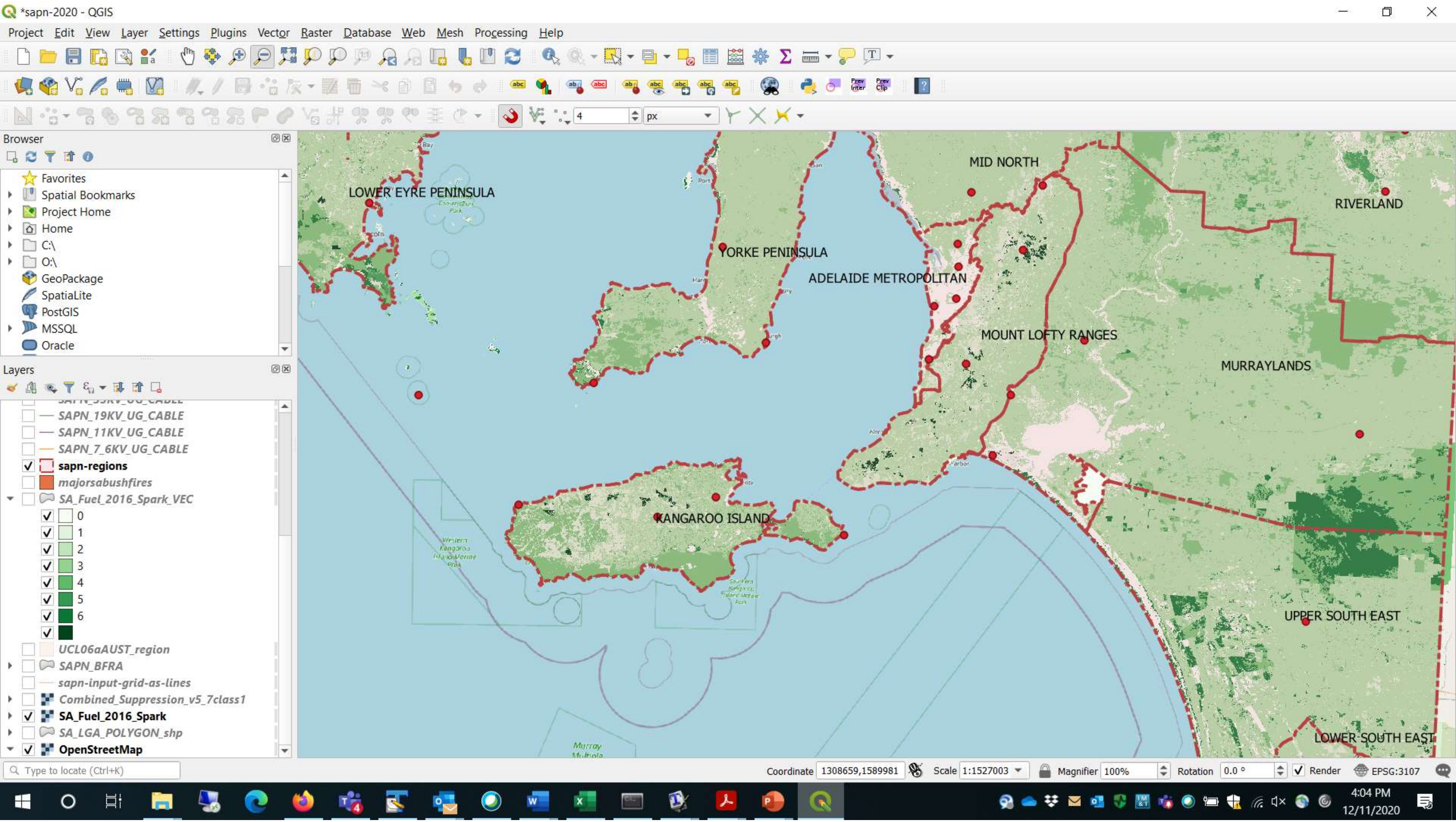
Fire simulation

- Simulation is necessary for fire, so that we can assess how elements interact

Bushfire simulations

- Fast bushfire simulations (like Spark, Phoenix and Wildfire Analyst) take *fire weather*, *fuel types* and *fuel loads* as inputs
- A quasi steady-state fire condition is calculated at each point on the current fire front, using these variables, and the front is incremented




*sapn-2020 - QGIS
Project Edit View Layer Settings Plugins Vector Raster Database Web Mesh Processing Help
Browser
Favorites
Spatial Bookmarks
Project Home
Home
C:\
O:\
GeoPackage
SpatiaLite
PostGIS
MSSQL
Oracle
Layers
SAPN_19KV_UG_CABLE
SAPN_11KV_UG_CABLE
SAPN_7_6KV_UG_CABLE
sapn-regions
majorsabushfires
SA_Fuel_2016_Spark_VEC
0
1
2
3
4
5
6
UCL06aAUST_region
SAPN_BFRA
sapn-input-grid-as-lines
Combined_Suppression_v5_7class1
SA_Fuel_2016_Spark
SA_LGA_POLYGON_shp
OpenStreetMap
LOWER EYRE PENINSULA
YORKE PENINSULA
MID NORTH
RIVERLAND
ADELAIDE METROPOLITAN
MOUNT LOFTY RANGES
MURRAYLANDS
KANGAROO ISLAND
UPPER SOUTH EAST
LOWER SOUTH EAST
Type to locate (Ctrl+K)
Coordinate 1308659,1589981
Scale 1:1527003
Magnifier 100%
Rotation 0.0 °
Render
EPSG:3107
4:04 PM
12/11/2020

Spark Wildfire propagation

Predicts the movement of the fire perimeter

- Based on empirical equations for rate-of-spread
- Multiple fuel types
- Time series or gridded weather data

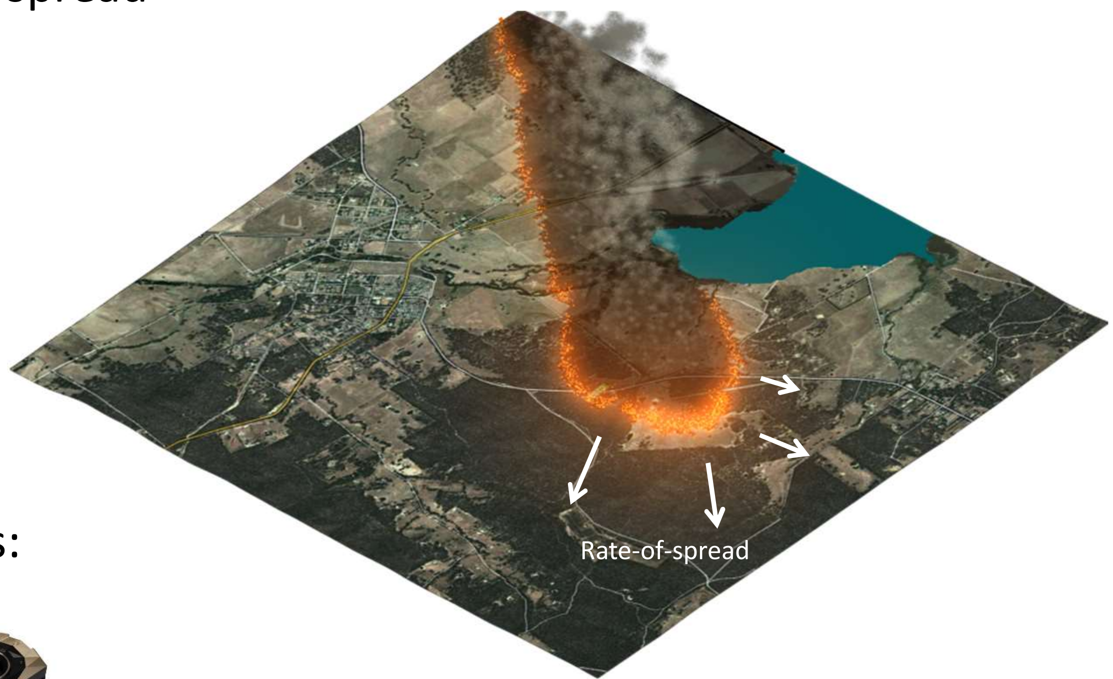
Based on level set formulation

- Precise control of rate-of-spread
- Implicit handling of merging interfaces
- Parallelisable

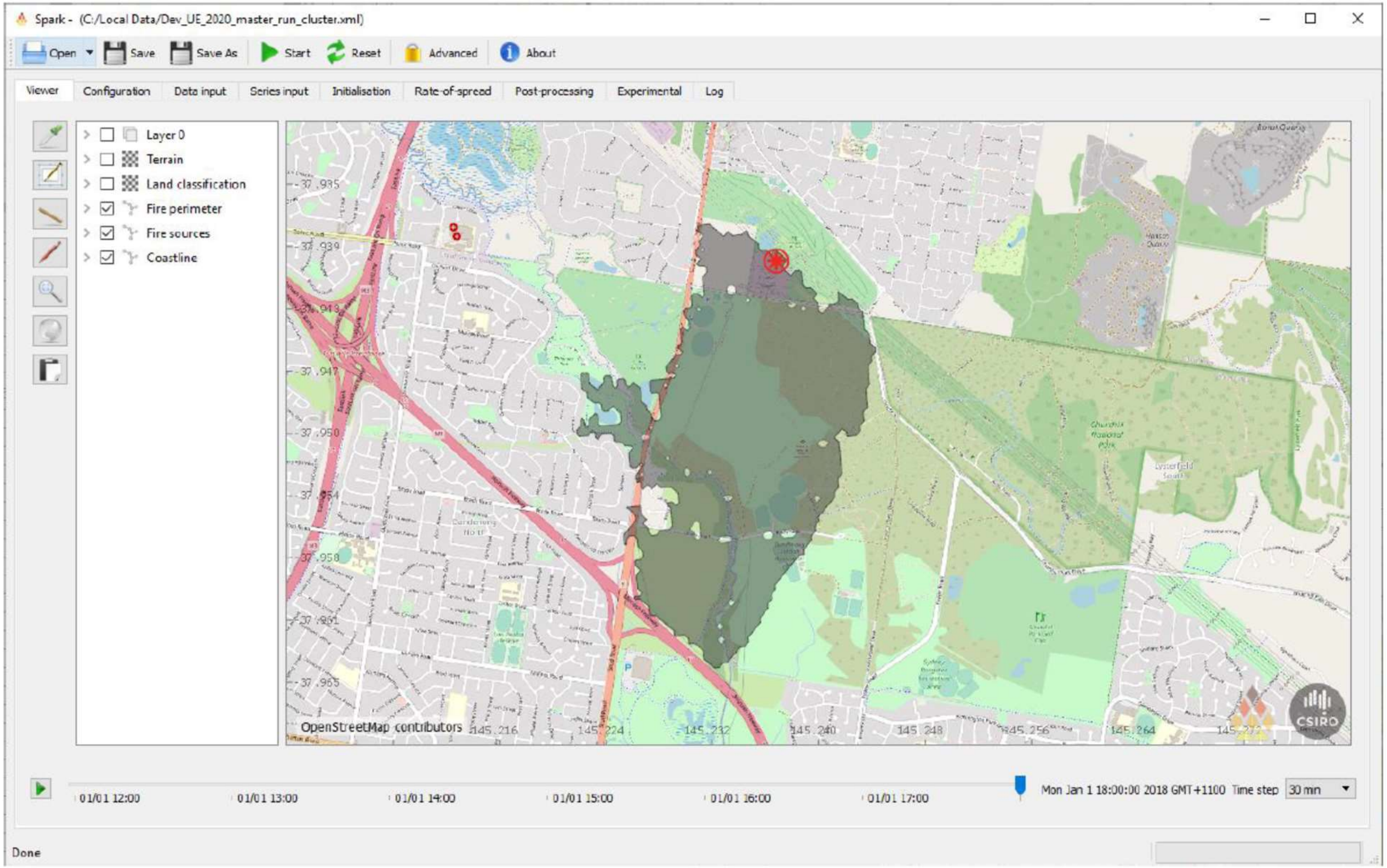
Use cloud and/or graphical processing units:

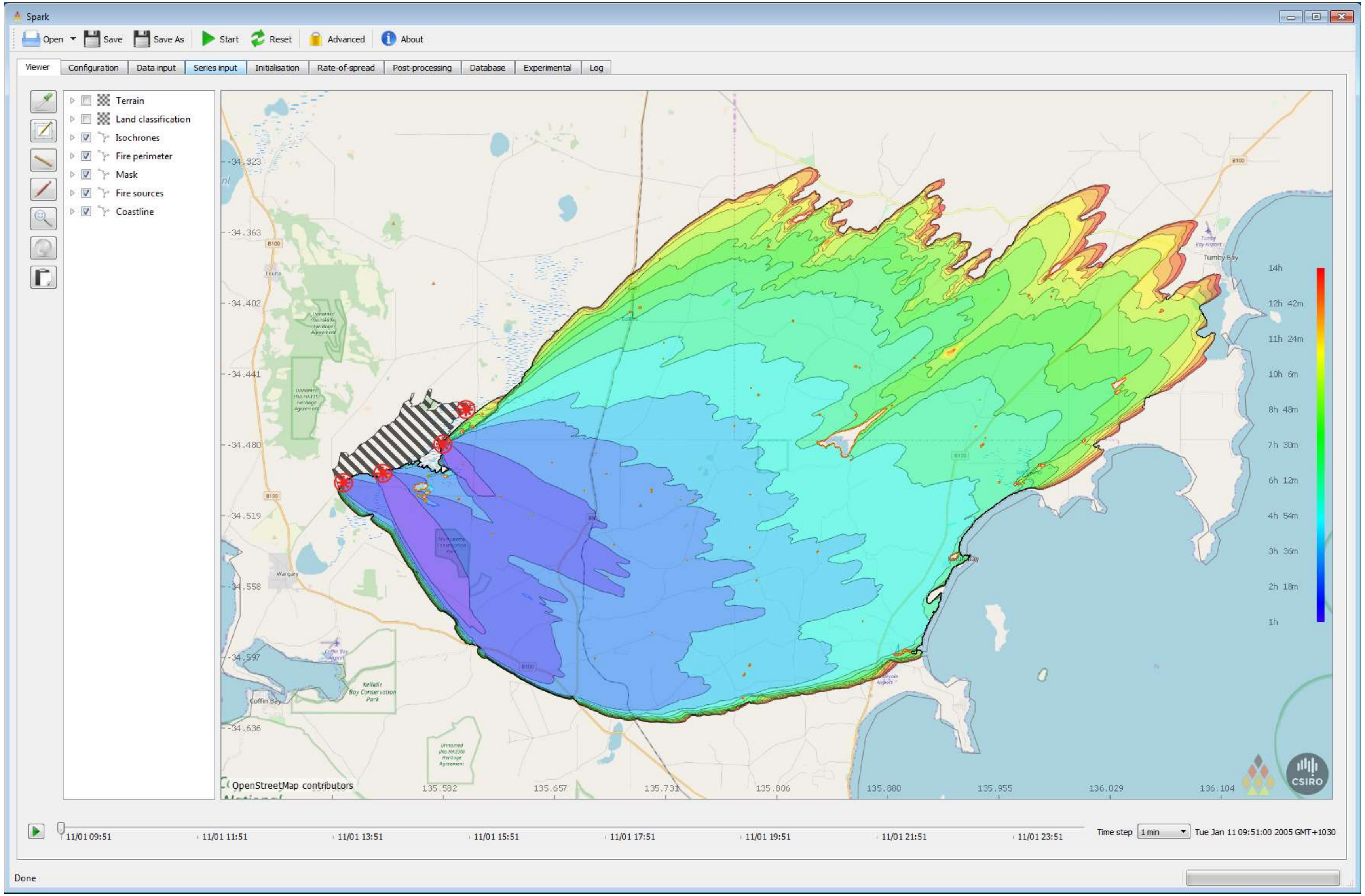
2000: ASCI White: 12.3 TFLOPS, $110M

2018: GTX Titan V: 14.9 TFLOPS, $3k

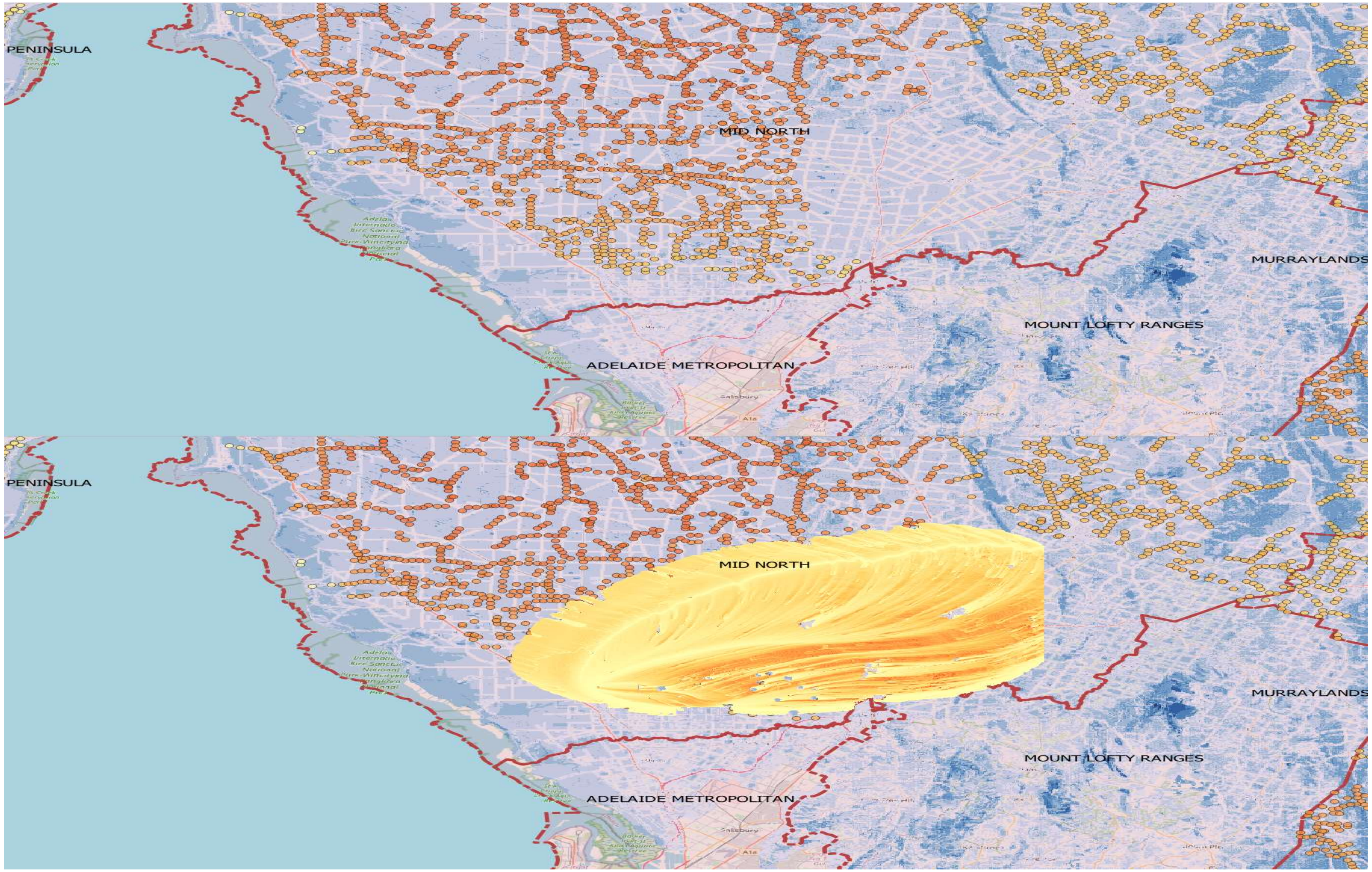


CSIRO


Spark - (C:/Local Data/Dev_UE_2020_master_run_cluster.xml)
Open
Save
Save As
Start
Reset
Advanced
About
Viewer
Configuration
Data input
Series input
Initialisation
Rate-of-spread
Post-processing
Experimental
Log
Layer 0
Terrain
Land classification
Fire perimeter
Fire sources
Coastline
OpenStreetMap contributors
01/01 12:00
01/01 13:00
01/01 14:00
01/01 15:00
01/01 16:00
01/01 17:00
Mon Jan 1 18:00:00 2018 GMT+1100
Time step
30 mn
Done
CSIRO



Spark
Open
Save
Save As
Start
Reset
Advanced
About
Viewer
Configuration
Data input
Series input
Initialisation
Rate-of-spread
Post-processing
Database
Experimental
Log
Terrain
Land classification
Isochrones
Fire perimeter
Mask
Fire sources
Coastline
-34.323
-34.363
-34.402
-34.441
-34.480
-34.519
-34.558
-34.597
-34.636
135.582
135.657
135.731
135.806
135.880
135.955
136.029
136.104
14h
12h 42m
11h 24m
10h 6m
8h 48m
7h 30m
6h 12m
4h 54m
3h 36m
2h 18m
1h
Tumby Bay
Coffin Bay
Kellidie Bay Conservation Park
© OpenStreetMap contributors
CSIRO
11/01 09:51
11/01 11:51
11/01 13:51
11/01 15:51
11/01 17:51
11/01 19:51
11/01 21:51
11/01 23:51
Time step
1 min
Tue Jan 11 09:51:00 2005 GMT+1030
Done

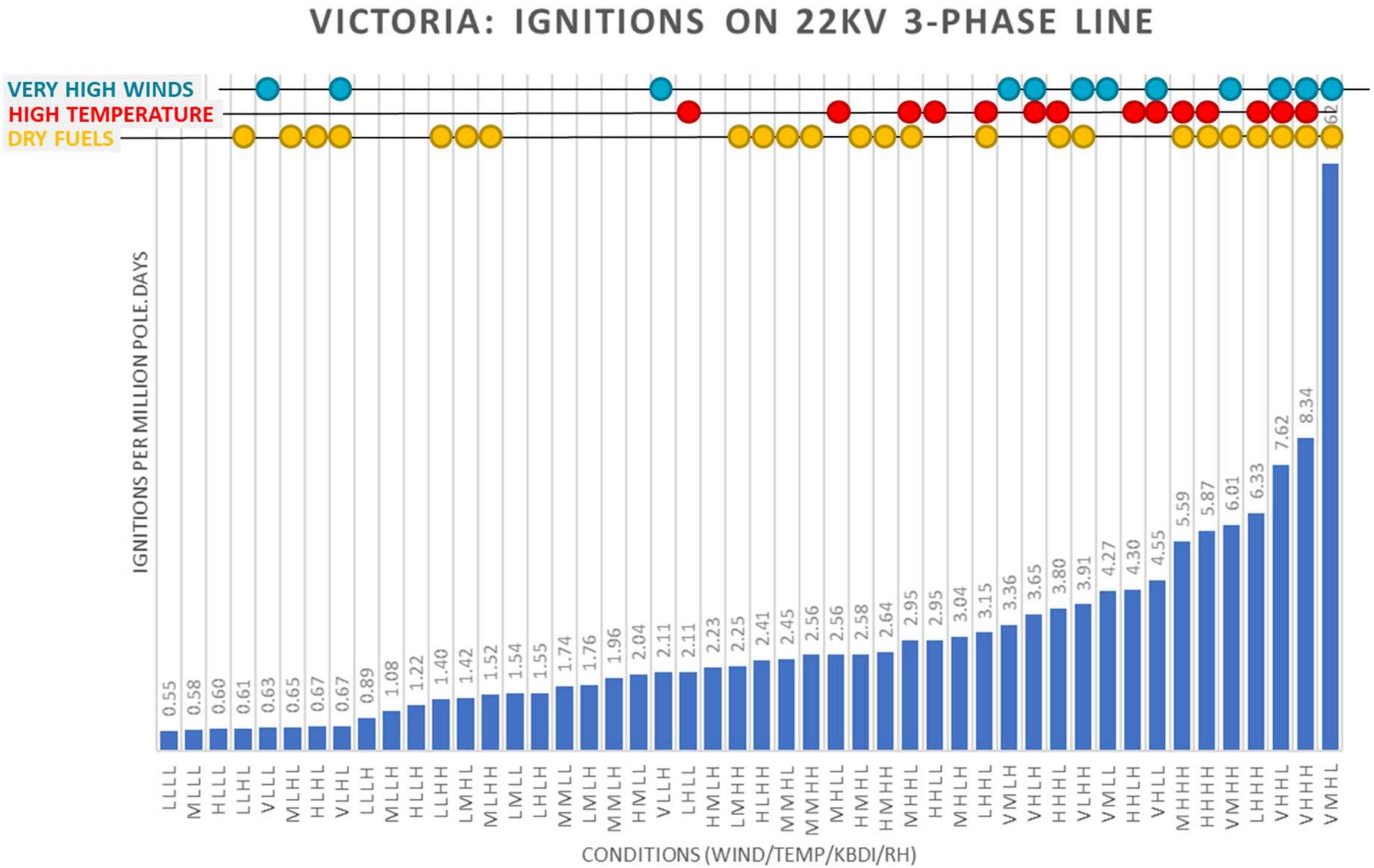


PENINSULA
MID NORTH
MURRAYLANDS
MOUNT LOFTY RANGES
ADELAIDE METROPOLITAN
PENINSULA
MID NORTH
MURRAYLANDS
MOUNT LOFTY RANGES
ADELAIDE METROPOLITAN

Risk analysis

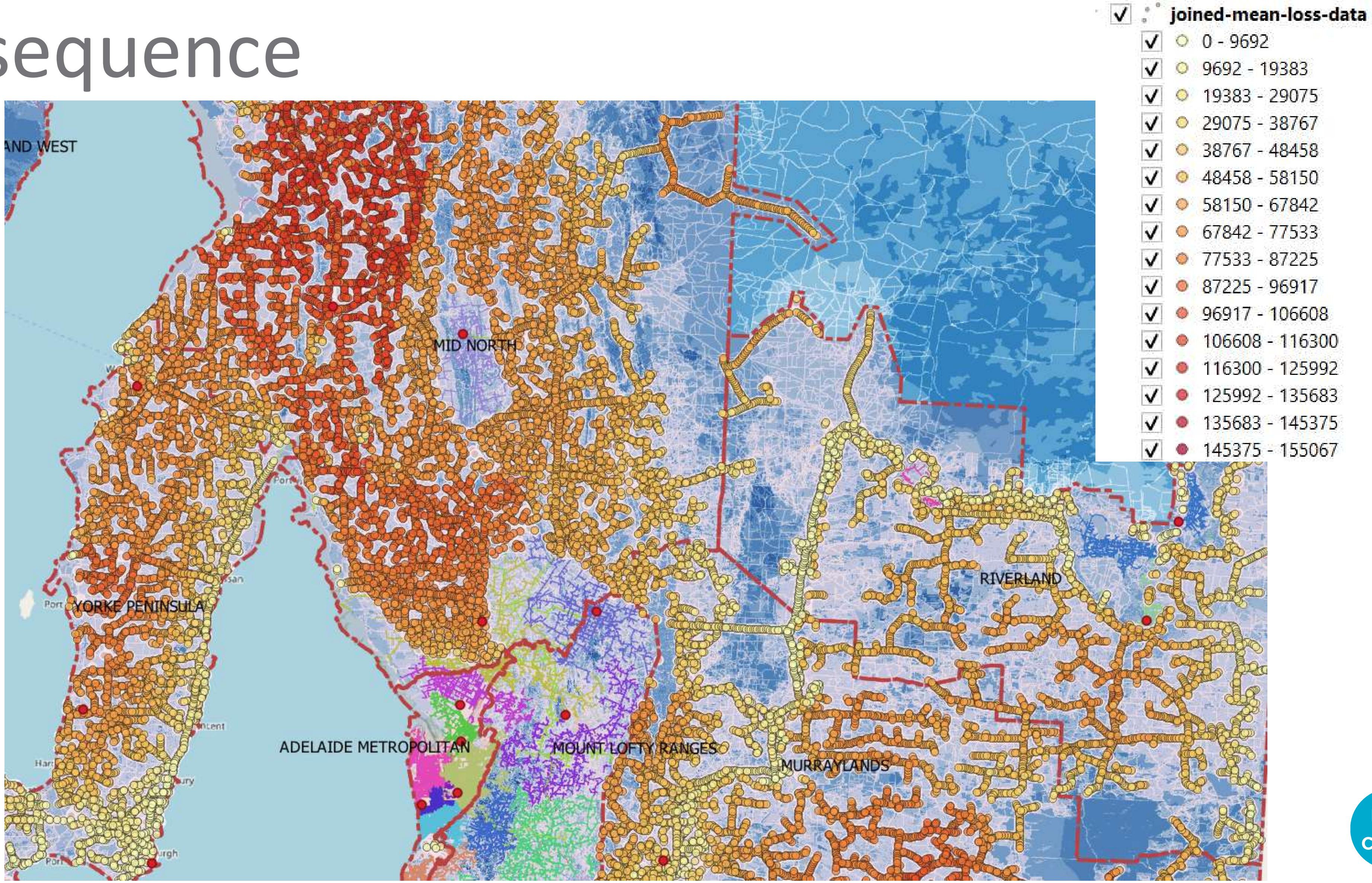
- Current risk exposure
- Risk Mitigation
  - Expert-driven decisions
  - Optimisation-driven decisions
- Risk = Likelihood × Consequence
  - if interested in expected losses
- Risk ≈ Likelihood of a major blaze × Consequence of a major blaze
  - threat > ignition > escalation
- Risk is highly dependent on:
  - Location
  - Weather and state of the fuel

Likelihood



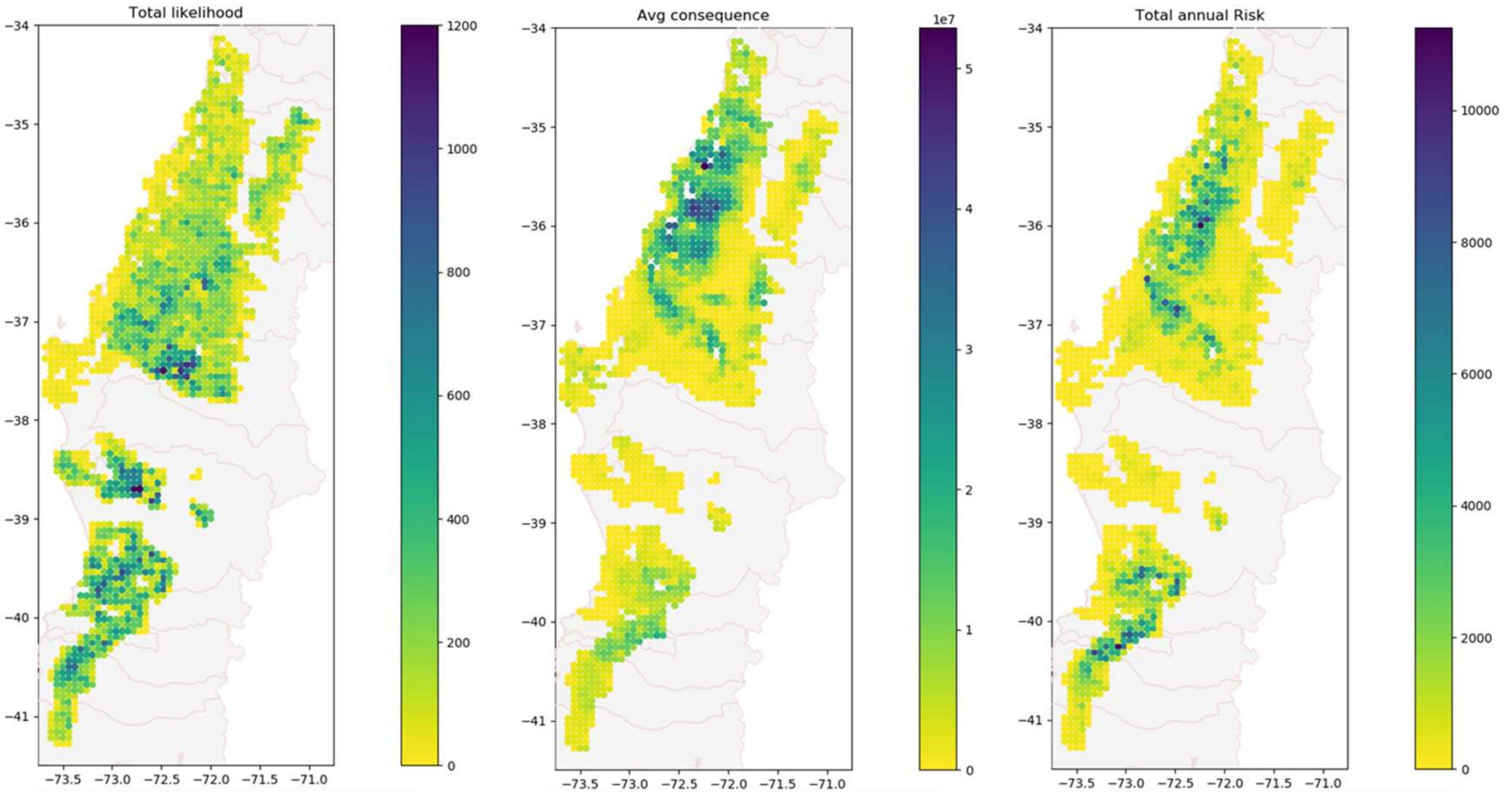
VICTORIA: IGNITIONS ON 22KV 3-PHASE LINE
VERY HIGH WINDS
HIGH TEMPERATURE
DRY FUELS
IGNITIONS PER MILLION POLE.DAYS
0.55
0.58
0.60
0.61
0.63
0.65
0.67
0.67
0.89
1.08
1.22
1.40
1.42
1.52
1.54
1.55
1.74
1.76
1.96
2.04
2.11
2.11
2.23
2.25
2.41
2.45
2.56
2.56
2.58
2.64
2.95
2.95
3.04
3.15
3.36
3.65
3.80
3.91
4.27
4.30
4.55
5.59
5.87
6.01
6.33
7.62
8.34
LLLL
MLLL
HLLL
LLHL
VLLL
MLHL
HLHL
VLHL
LLLH
MLLH
HLLH
LLHH
LMHL
MLHH
LMLL
LHLH
MMLL
LMLH
MMLH
HMLL
VLLH
LHLL
HMLH
LMHH
HLHH
MMHL
MMHH
MHLL
HMHL
HMHH
MHHL
HHLL
MHLH
LHHL
VMLH
VHLH
HHHL
VLHH
VMLL
HHLH
VHLL
MHHH
HHHH
VMHH
LHHH
VHHL
VHHH
VMHL
CONDITIONS (WIND/TEMP/KBDI/RH)

Consequence



CSIRO

Where to prioritize investment in mitigation?



TOTAL (100Ha+) LIKELIHOOD

AVERAGE CONSEQUENCE

TOTAL RISK

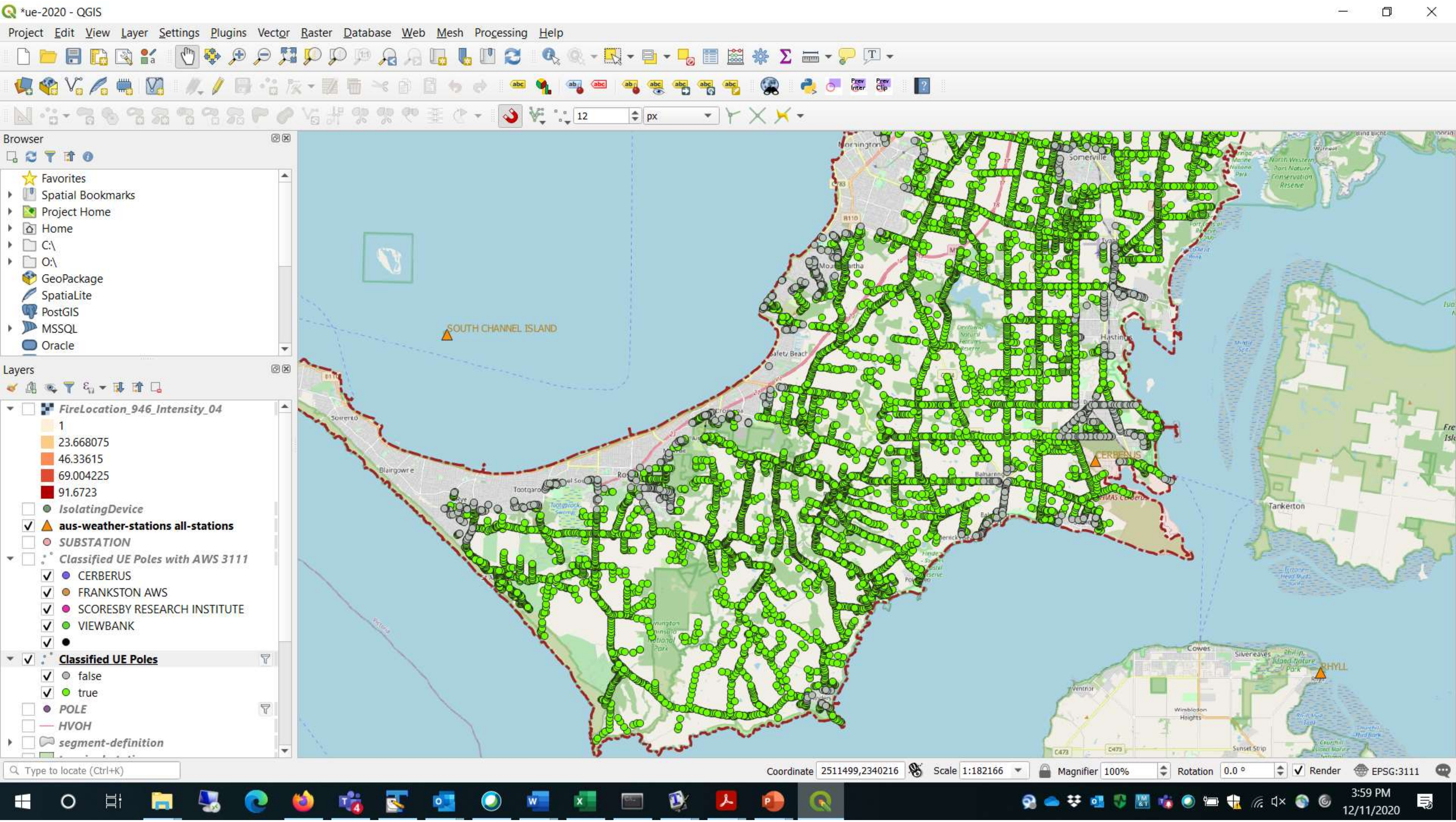
CSIRO

Ensemble simulations

- 10^4 to 10^7 individual simulations
- Set of points
  - Territory coverage is representative
- Set of weather streams
  - Temporal sequence of meteorological (fire weather) variables
  - Representative for the location (i.e., a weight)
  - Future weather (changing climate) by weight adjustments
- Ignition time of day
- Fire termination criteria
- No fire suppression

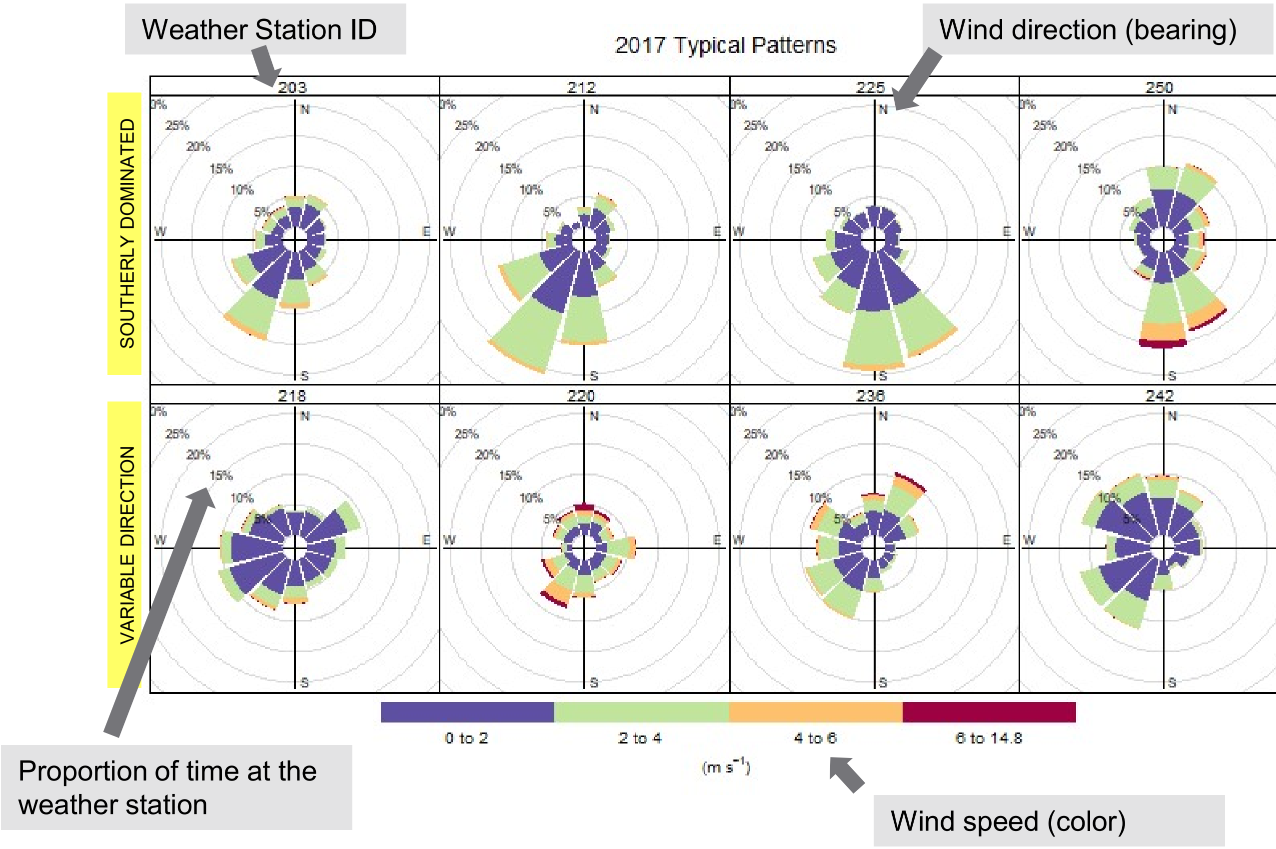
No suppression?

- **Yes it is true**, fire simulations don’t explicitly include fire suppression activities (firefighting)
- *Initial attack* versus *extended attack* firefighting
- Direct firefighting on the fire front, firefighting on the flank, clearing and backburning, asset protection
- Suppression is typically represented by:
  - Initial attack success probability
  - Losses not being 100% when a ‘pixel’ is impacted by fire
  - (Also: maximum fireline intensity at a pixels depends on whether it is a head fire or flank fire impact)

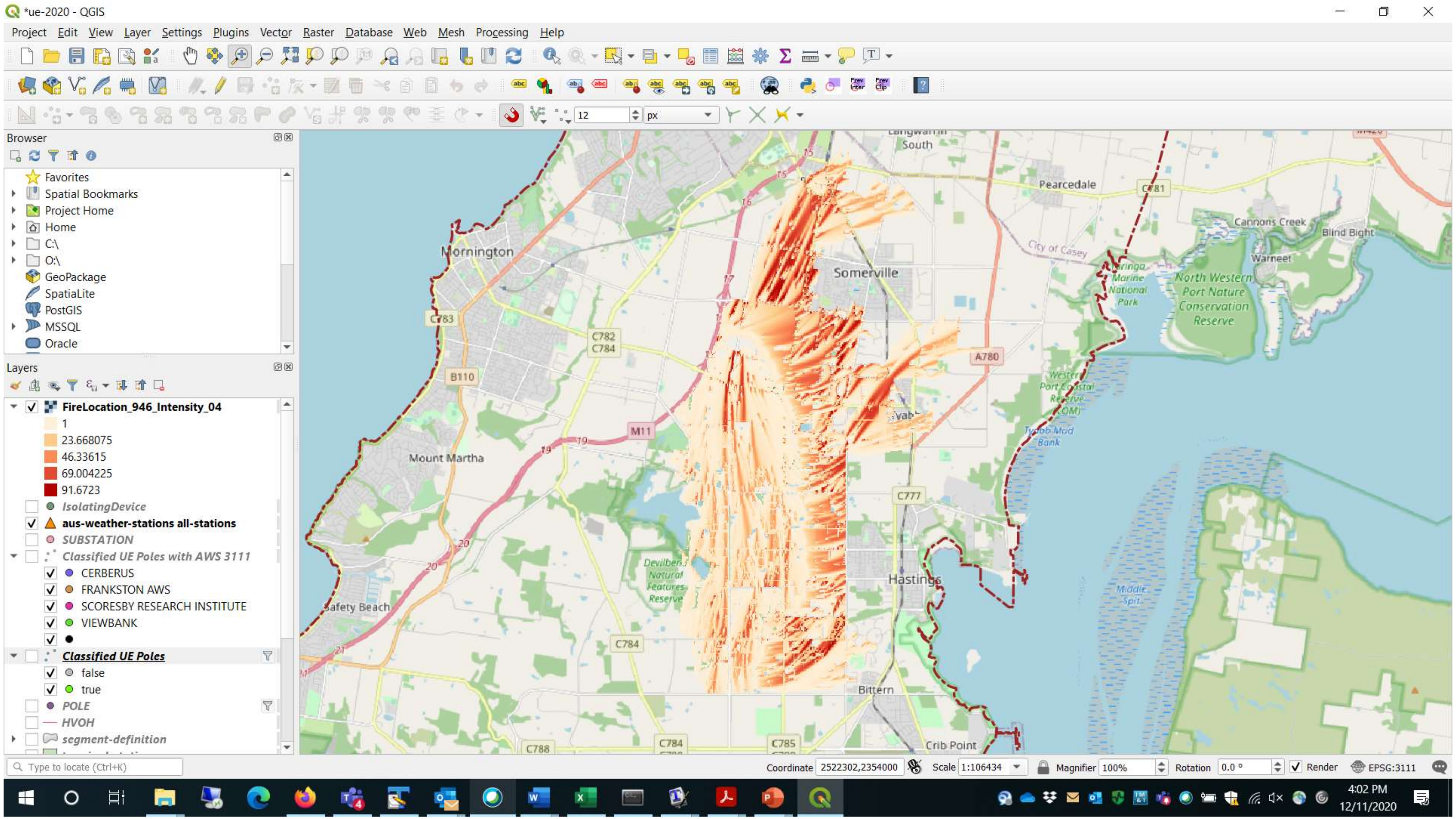

*ue-2020 - QGIS
Project Edit View Layer Settings Plugins Vector Raster Database Web Mesh Processing Help
Browser
Favorites
Spatial Bookmarks
Project Home
Home
C:\
O:\
GeoPackage
SpatiaLite
PostGIS
MSSQL
Oracle
Layers
FireLocation_946_Intensity_04
1
23.668075
46.33615
69.004225
91.6723
IsolatingDevice
aus-weather-stations all-stations
SUBSTATION
Classified UE Poles with AWS 3111
CERBERUS
FRANKSTON AWS
SCORESBY RESEARCH INSTITUTE
VIEWBANK
Classified UE Poles
false
true
POLE
HVOH
segment-definition
SOUTH CHANNEL ISLAND
CERBERUS
RHYLL
Sorrento
Blairgowrie
Tootgarook
Somerville
Hastings
Balnarring
Tankerton
Cowes
Silverleaves
Wimbledon Heights
Sunset Strip
Type to locate (Ctrl+K)
Coordinate 2511499,2340216
Scale 1:182166
Magnifier 100%
Rotation 0.0 °
Render
EPSG:3111
3:59 PM
12/11/2020

Fire weather analysis

- Analysis of wind speeds and directions (windrose analysis - see right) to understand 'typical' patterns to inform the representative selection of past weather

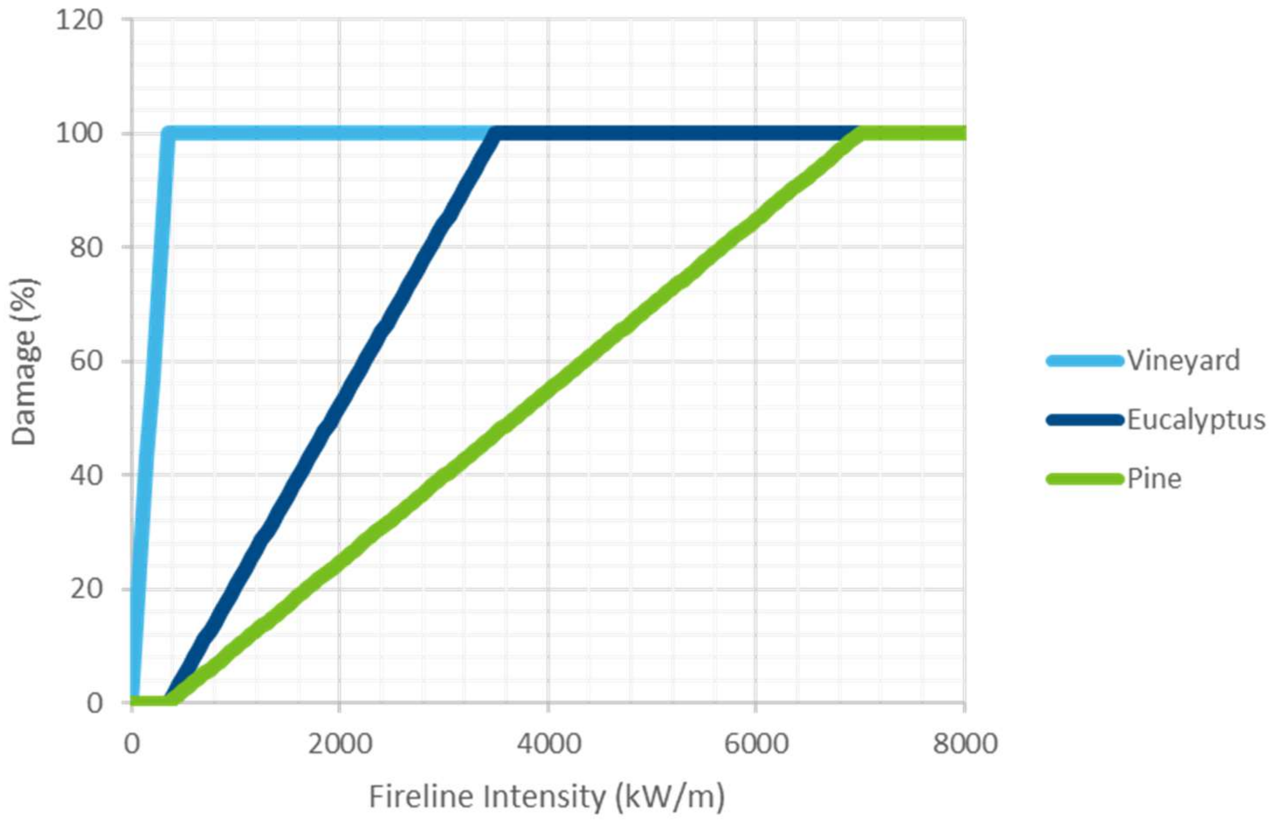


Fireline intensity

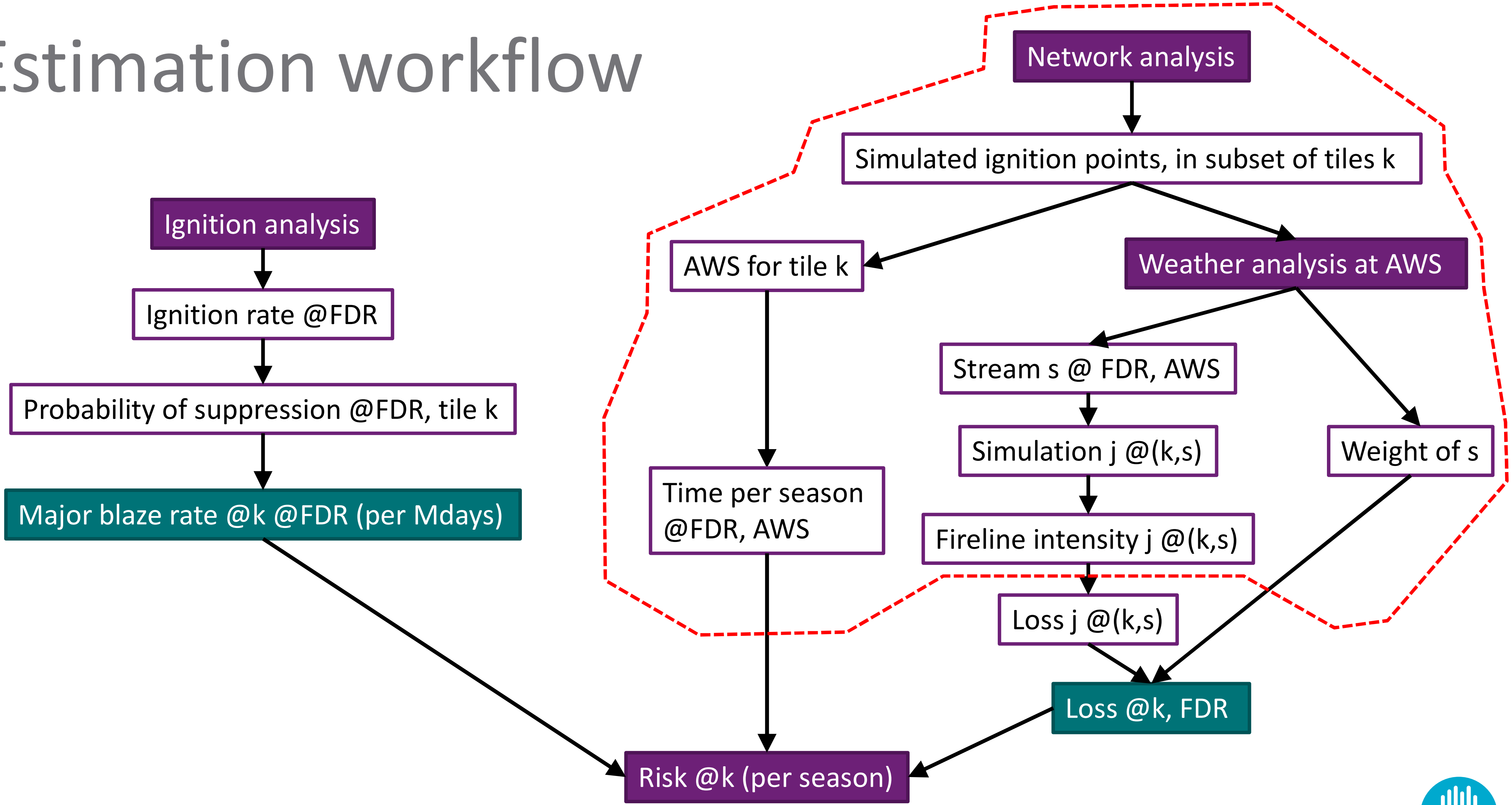


Loss functions

- Fireline intensity kW/m
- Convert to loss % then $$
- Fireline intensity is a most important output from a fire simulation when the focus is risk analysis



Estimation workflow



Analytics

- Optimisation
  - Selection of mitigations subject to a budget
  - Schedule of retiring risk
  - Representing suppression (incl. resource constrained scheduling)
  - Optimal selection of points and weather streams for ensembles
- Statistics and learning
  - Ignition rates over time and space
  - Prediction of loss at tile k under conditions $C(t)$ at ignition time-of-day t_0
  - Fire at the urban interface

Resources

- Fuel maps
  - ALUM
  - DELWP (Victoria), DEWNR (South Australia), …
- Loss functions
  - Literature
  - Educated guesses
- Fire simulators
  - Phoenix Rapidfire
  - CSIRO Spark
- Cloud computing resources
  - Necessary!
  - $2000 to $8000 for a major ensemble run