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Evaluating Wildfire Simulators using Historical Fire Data

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School of Computer Science and Software Engineering, University of Western Australia

Thanks to Government of Western Australia and iiNet for travel funding

AUSTRALIS Wildfire Simulator

- predicts wildfire spread using fuel, weather, topography and rate-of-spread data
- allows predicted location of fire perimeters to be communicated via email, SMS and maps on web enabled mobile devices
- rapidly generates detailed future fire location
- Performance: 10km x 10km at 100m resolution (~7000 cells) in ~30s

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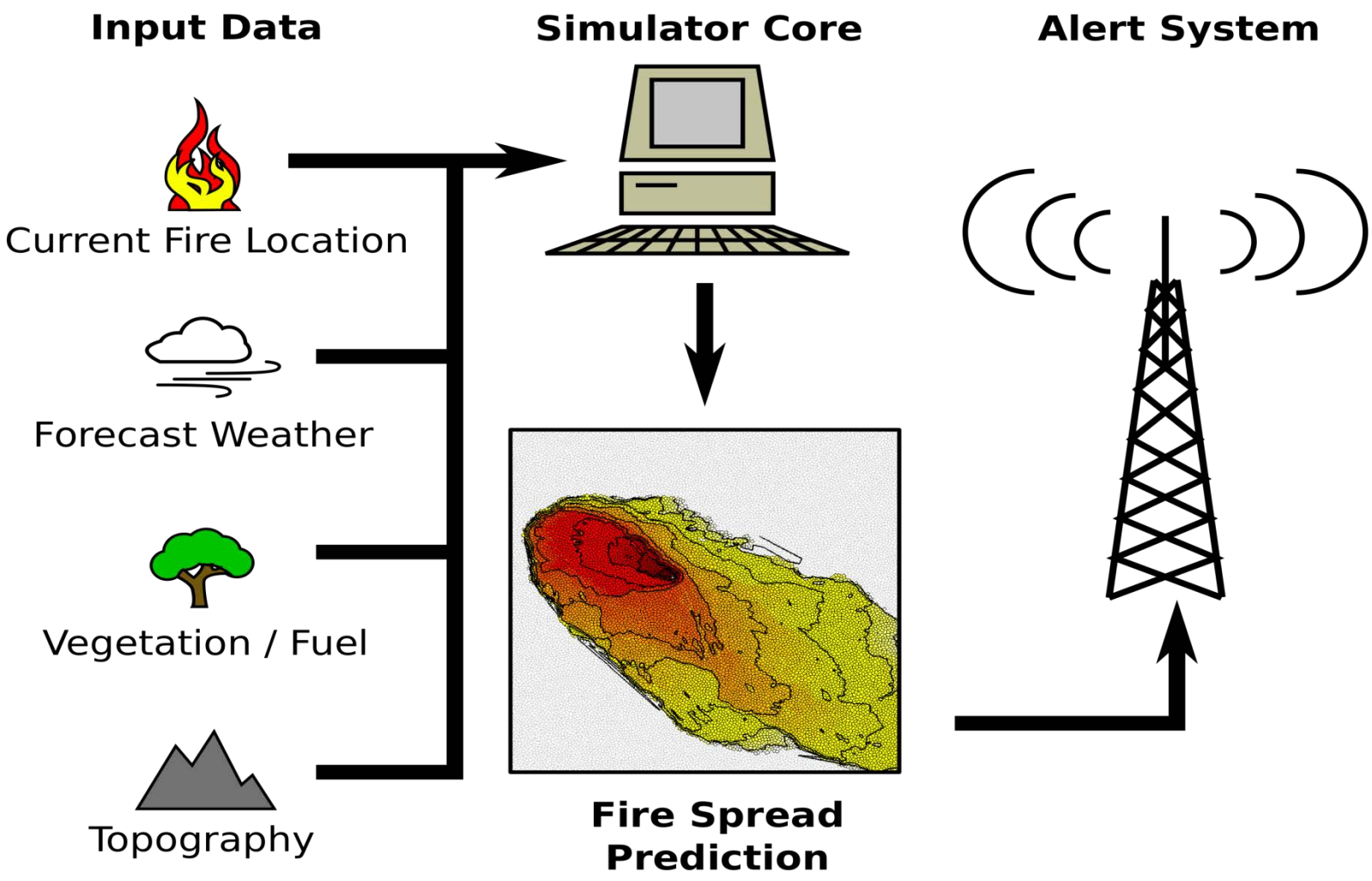
- Wildfires occur 12 months of the year in W. Australia, from Northern tropical savannah to S.W. temperate forest and (mostly) arid scrub.
- AUSTRALIS now used for all major fires in Western Australia.

Validation

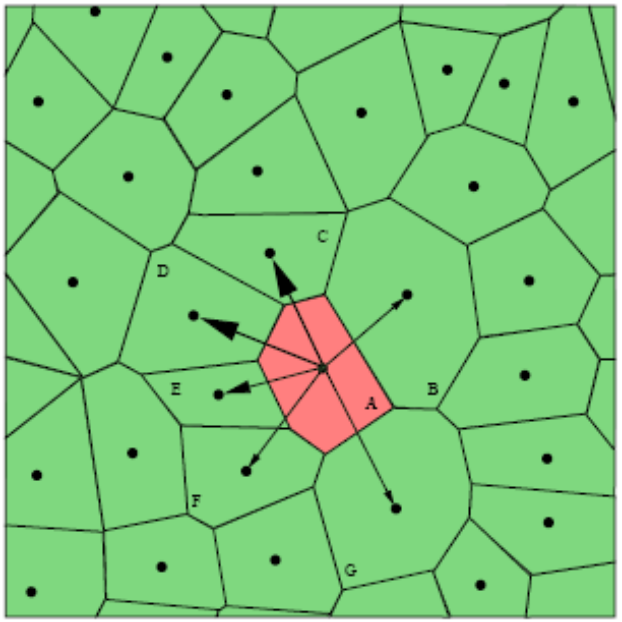
- Validation is necessary to:
  - test simulation algorithms and software
  - improve Fire Behaviour Models
  - increase confidence in simulator results
  - Validate by simulating as many historical fires as possible where good data is available
  - Challenge : sourcing high quality data from previous extreme fires

Simulator System Overview



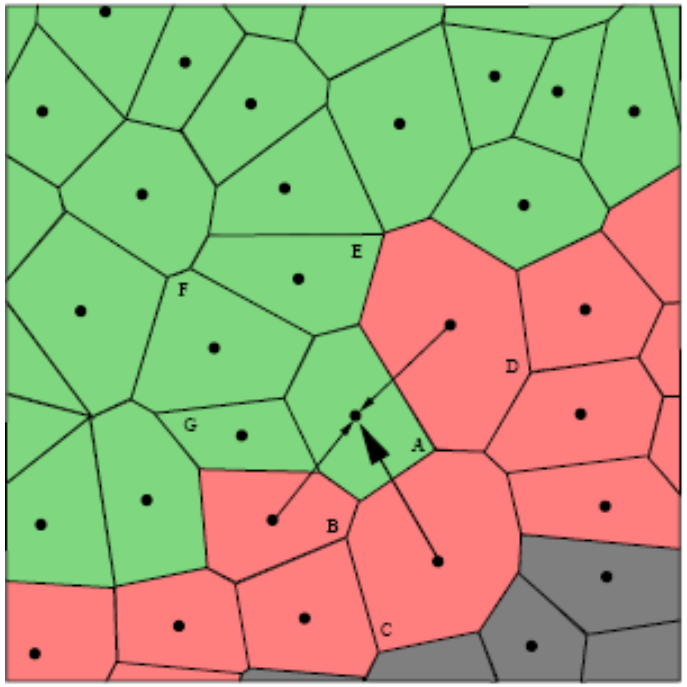
Fire Spread by Propagation Delay

- each cell has approximately 10 neighbours
- rate of spread calculated using fuel type, moisture, wind speed and direction
- distance and direction to each neighbour determines ignition time of neighbour from most recently ignited cell

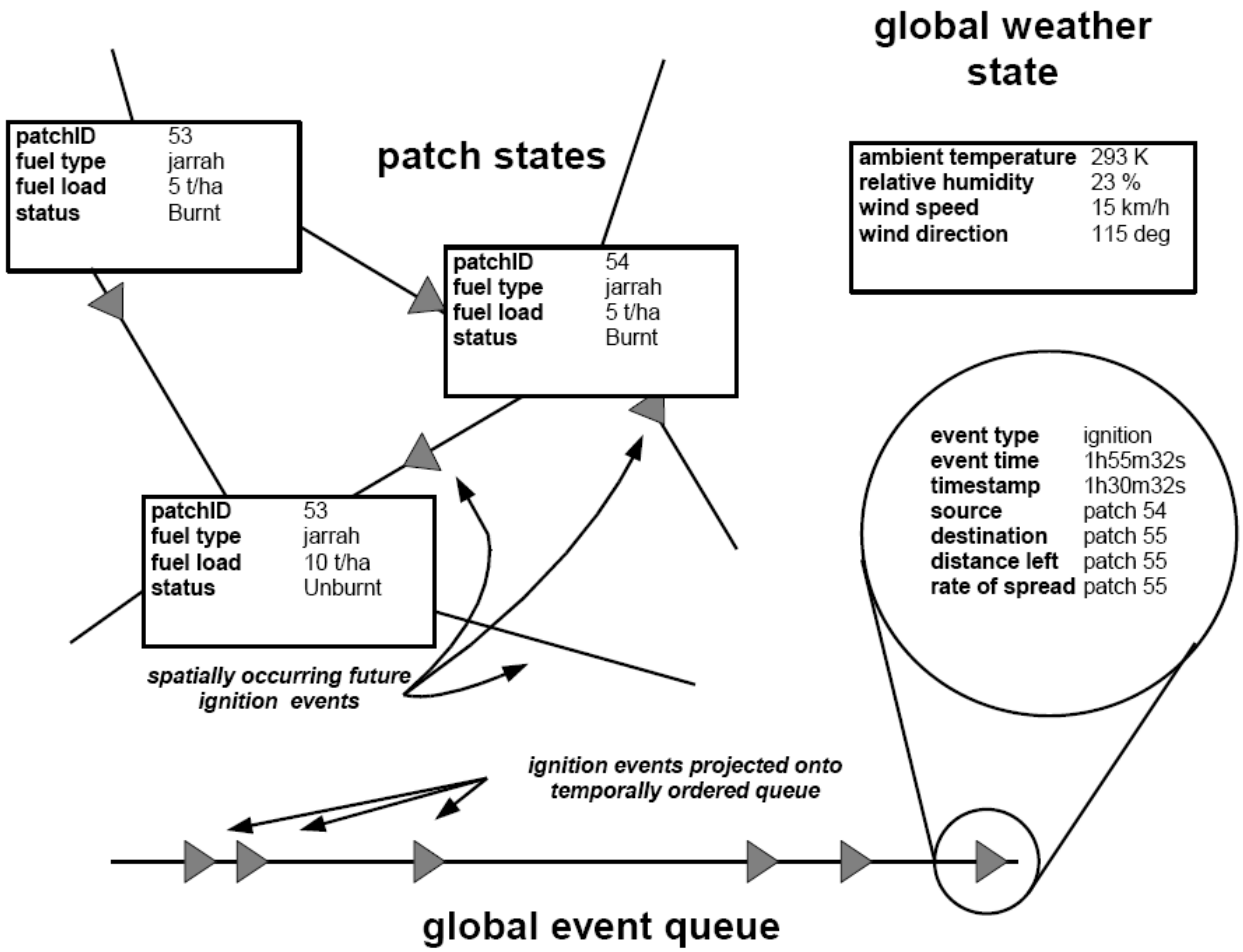


Spread over Landscape with wind from SE

- each cell in one of three states: *unburnt*, *burning* or *burnt*
- ignition changes the state of *unburnt* cells to *burning*
- when cell ignited, ignition of each of its unburnt neighbours is calculated and scheduled
- burnt cells cannot be re-ignited



Discrete Event Simulation



Australis Simulator Demonstration

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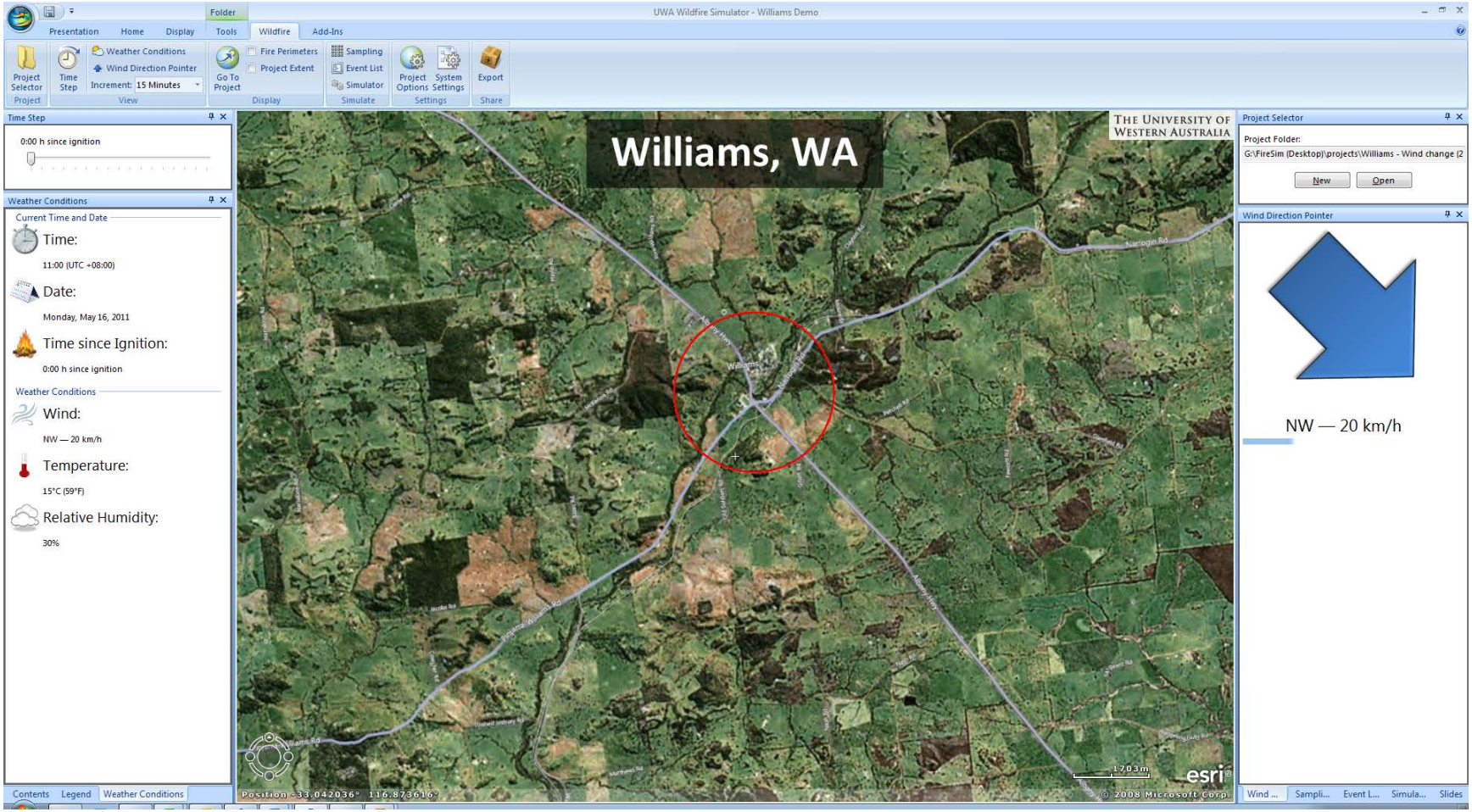

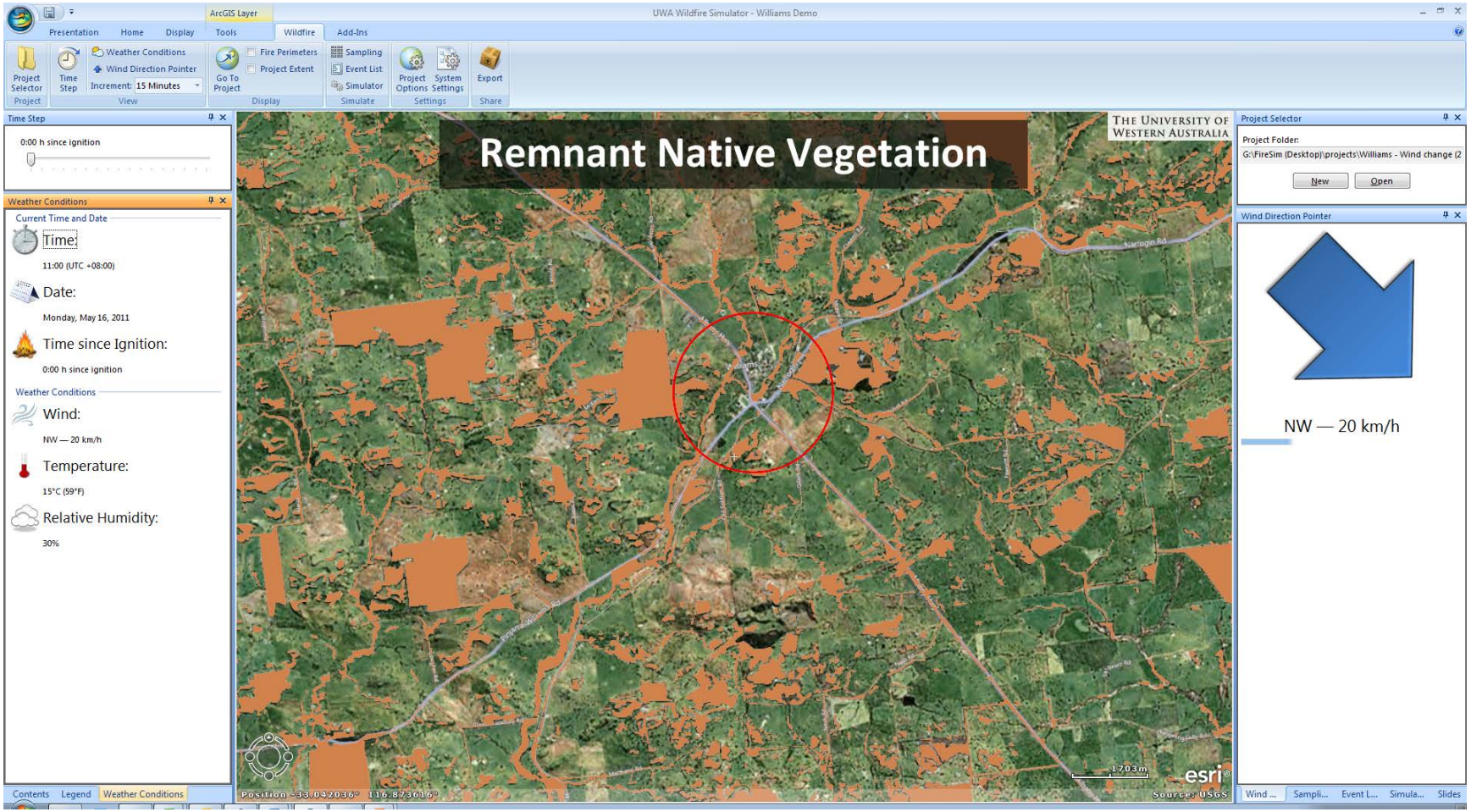
UWA Wildfire Simulator - Williams Demo
ArcGIS Layer
Presentation
Home
Display
Tools
Wildfire
Add-Ins
Project Selector
Time Step
Weather Conditions
Wind Direction Pointer
Increment: 15 Minutes
Go To Project
Fire Perimeters
Project Extent
Sampling
Event List
Simulator
Project Options
System Settings
Export
Time Step
0:00 h since ignition
Weather Conditions
Current Time and Date
Time:
11:00 (UTC +08:00)
Date:
Monday, May 16, 2011
Time since Ignition:
0:00 h since ignition
Weather Conditions
Wind:
NW — 20 km/h
Temperature:
15°C (59°F)
Relative Humidity:
30%
Contents
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Weather Conditions
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THE UNIVERSITY OF WESTERN AUSTRALIA
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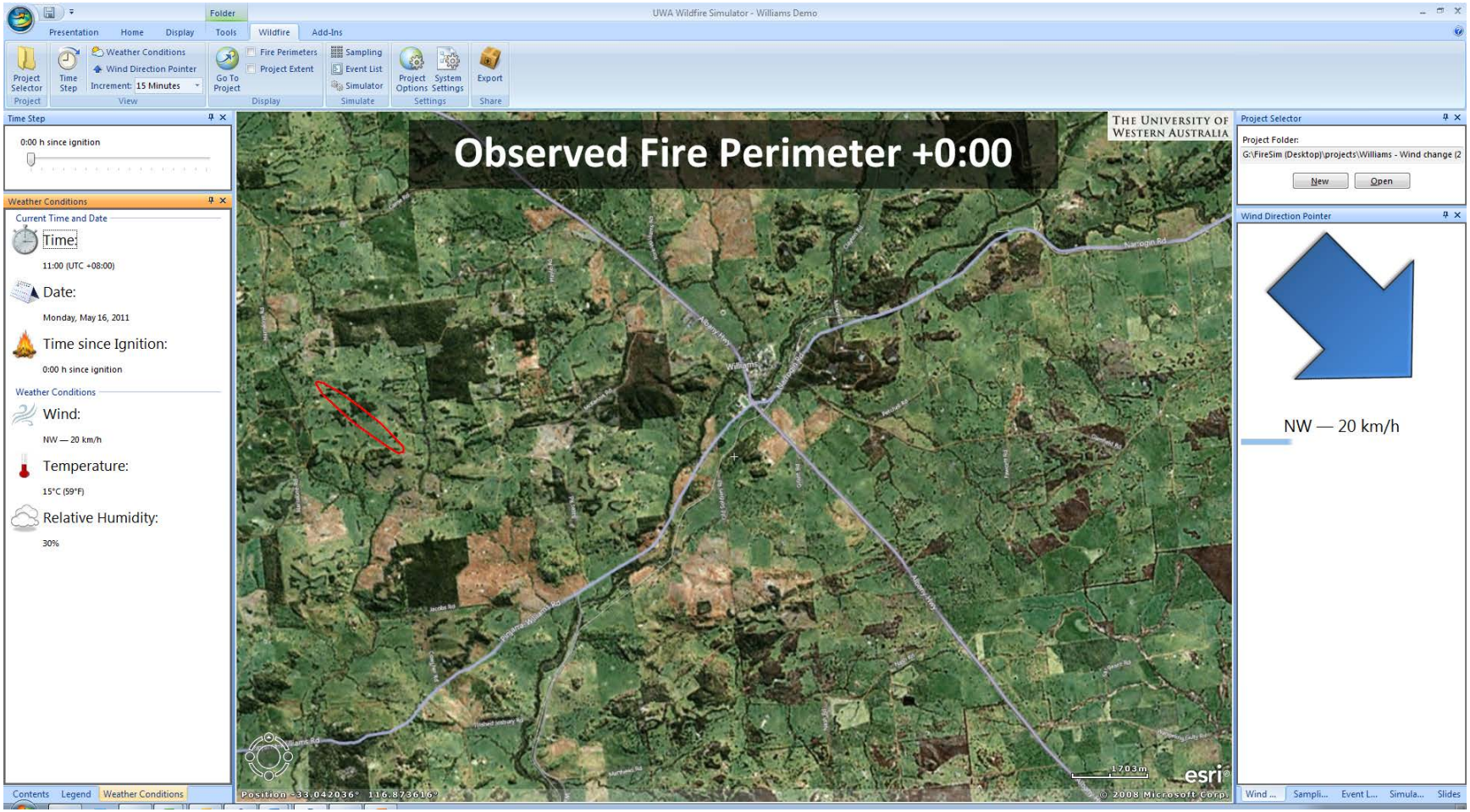
UWA Wildfire Simulator - Williams Demo
Observed Fire Perimeter +0:00
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Time Step
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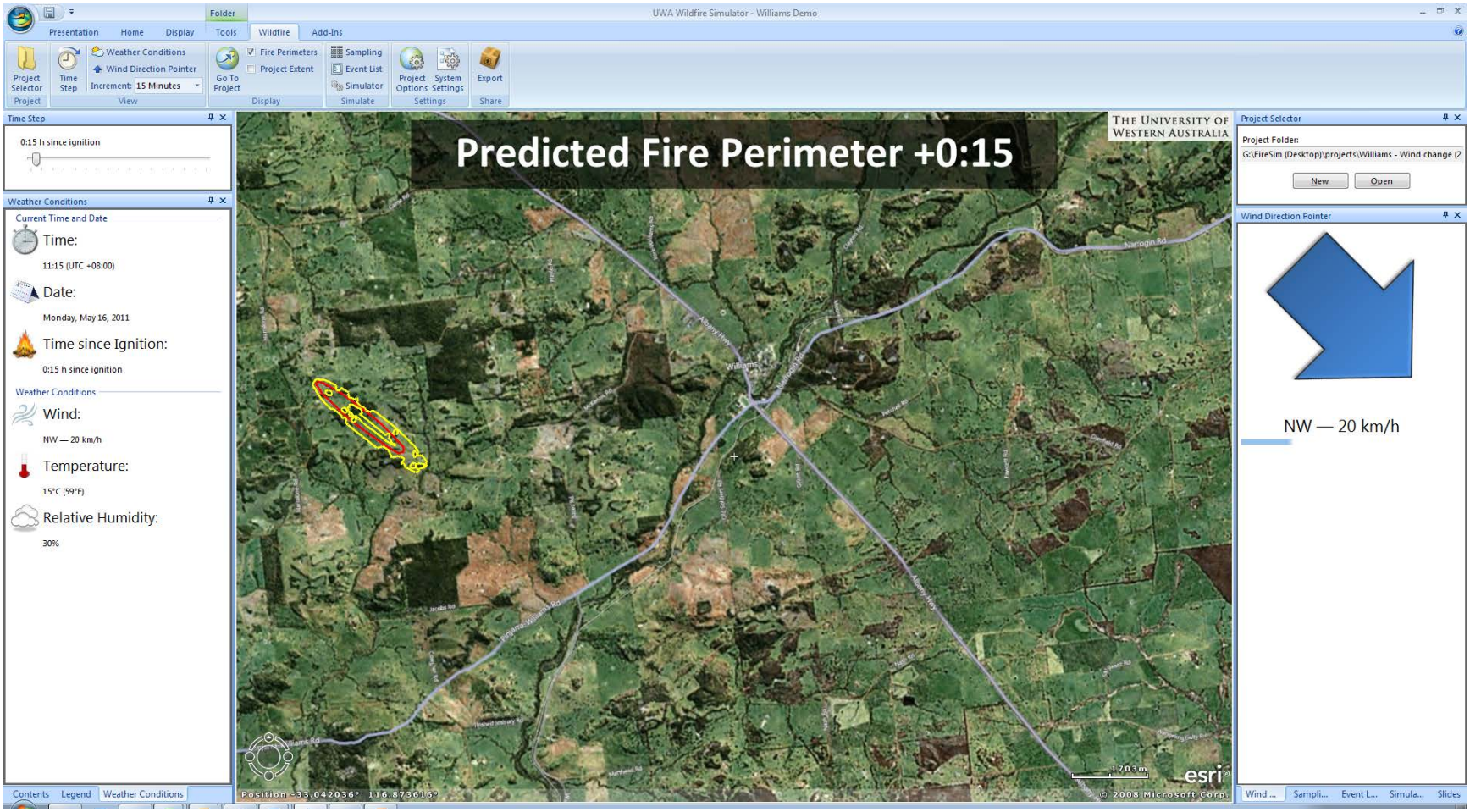
© 2008 Microsoft Corp.


UWA Wildfire Simulator - Williams Demo
Predicted Fire Perimeter +0:15
THE UNIVERSITY OF WESTERN AUSTRALIA
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0:15 h since ignition
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Monday, May 16, 2011
Time since Ignition:
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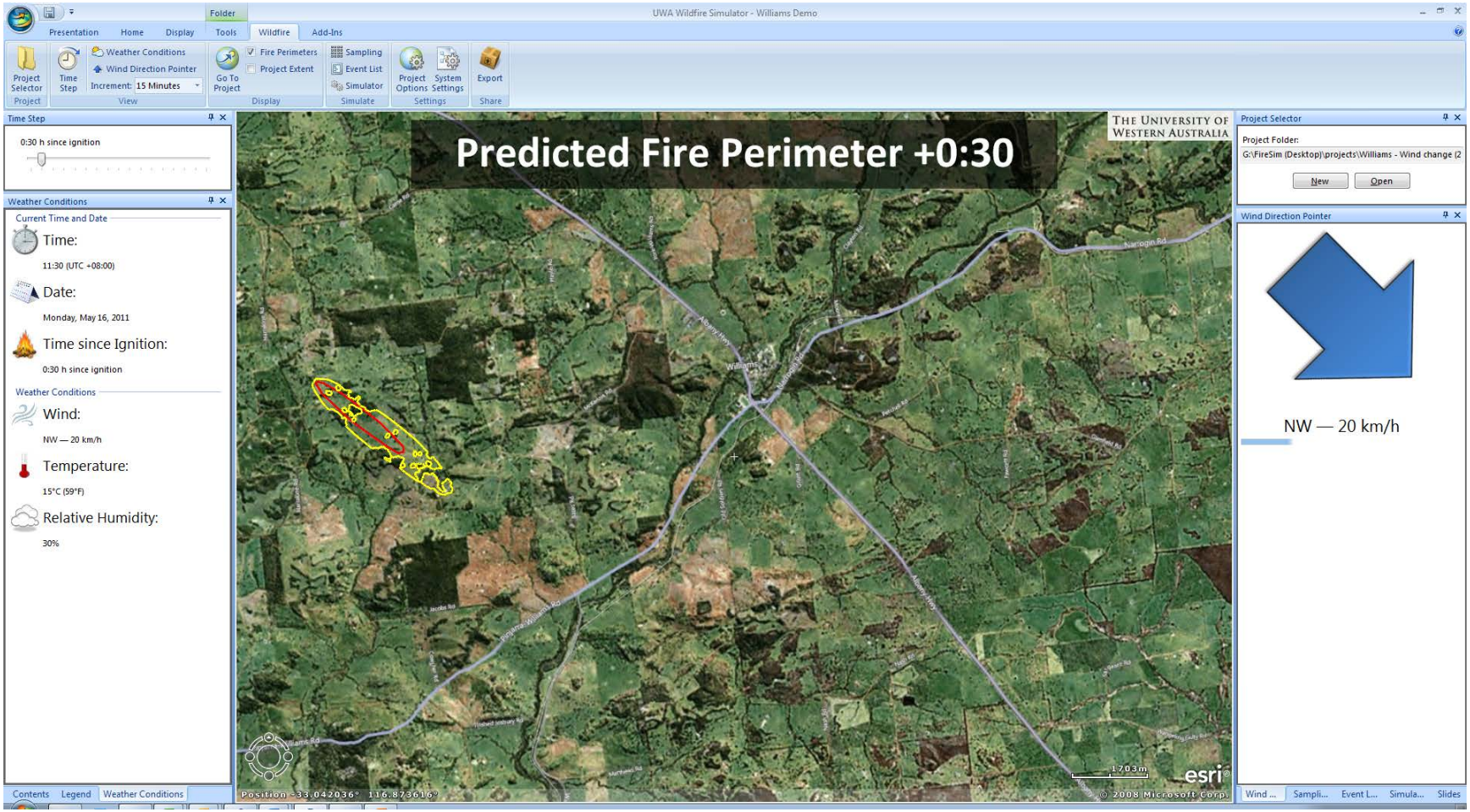
© 2008 Microsoft Corp.
Position -33.042036° 116.873616°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Predicted Fire Perimeter +0:30
THE UNIVERSITY OF WESTERN AUSTRALIA
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11:30 (UTC +08:00)
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Weather Conditions
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Temperature:
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Relative Humidity:
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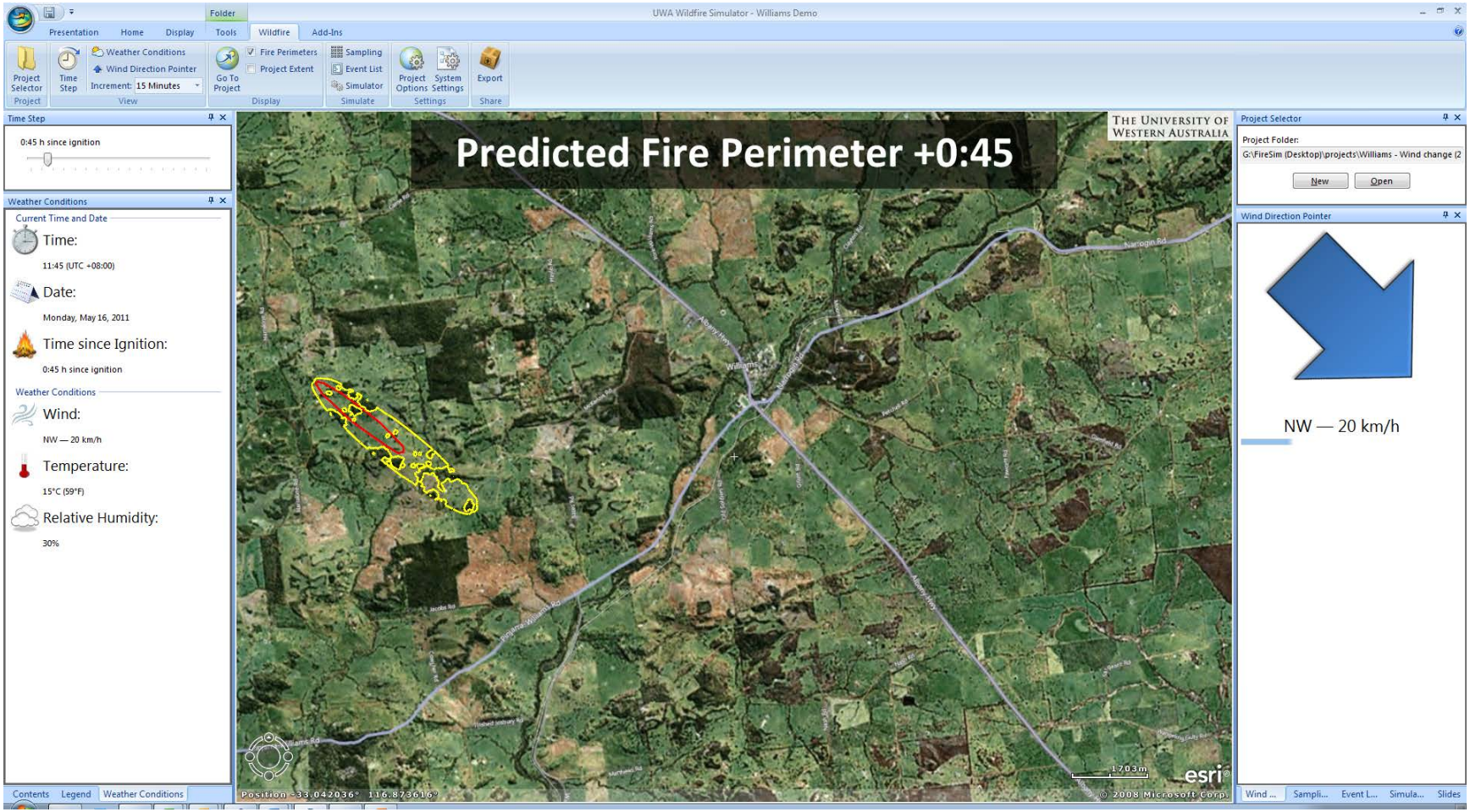
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Temperature:
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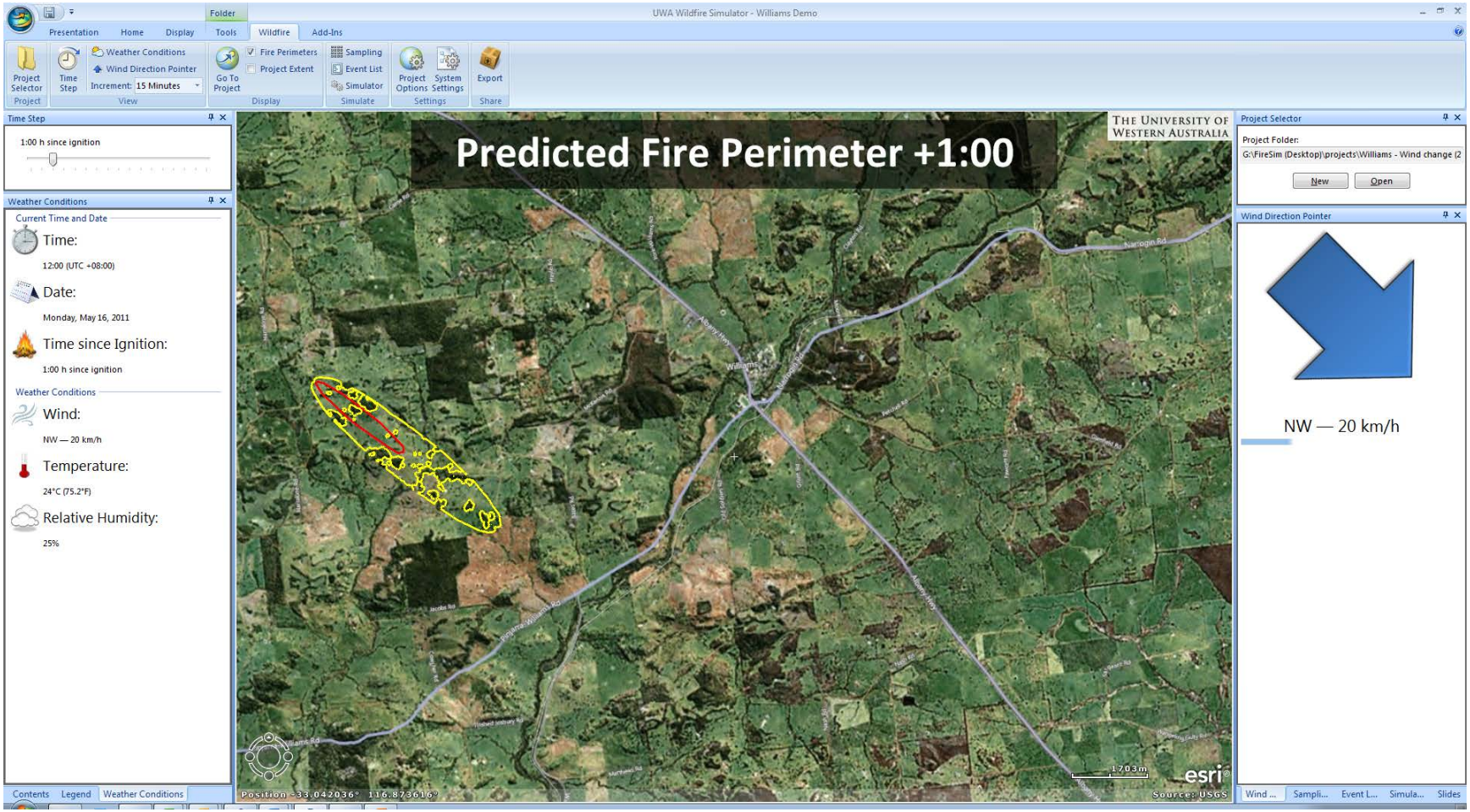
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Predicted Fire Perimeter +1:00
THE UNIVERSITY OF WESTERN AUSTRALIA
Time Step
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Weather Conditions
Current Time and Date
Time:
12:00 (UTC +08:00)
Date:
Monday, May 16, 2011
Time since Ignition:
1:00 h since ignition
Weather Conditions
Wind:
NW — 20 km/h
Temperature:
24°C (75.2°F)
Relative Humidity:
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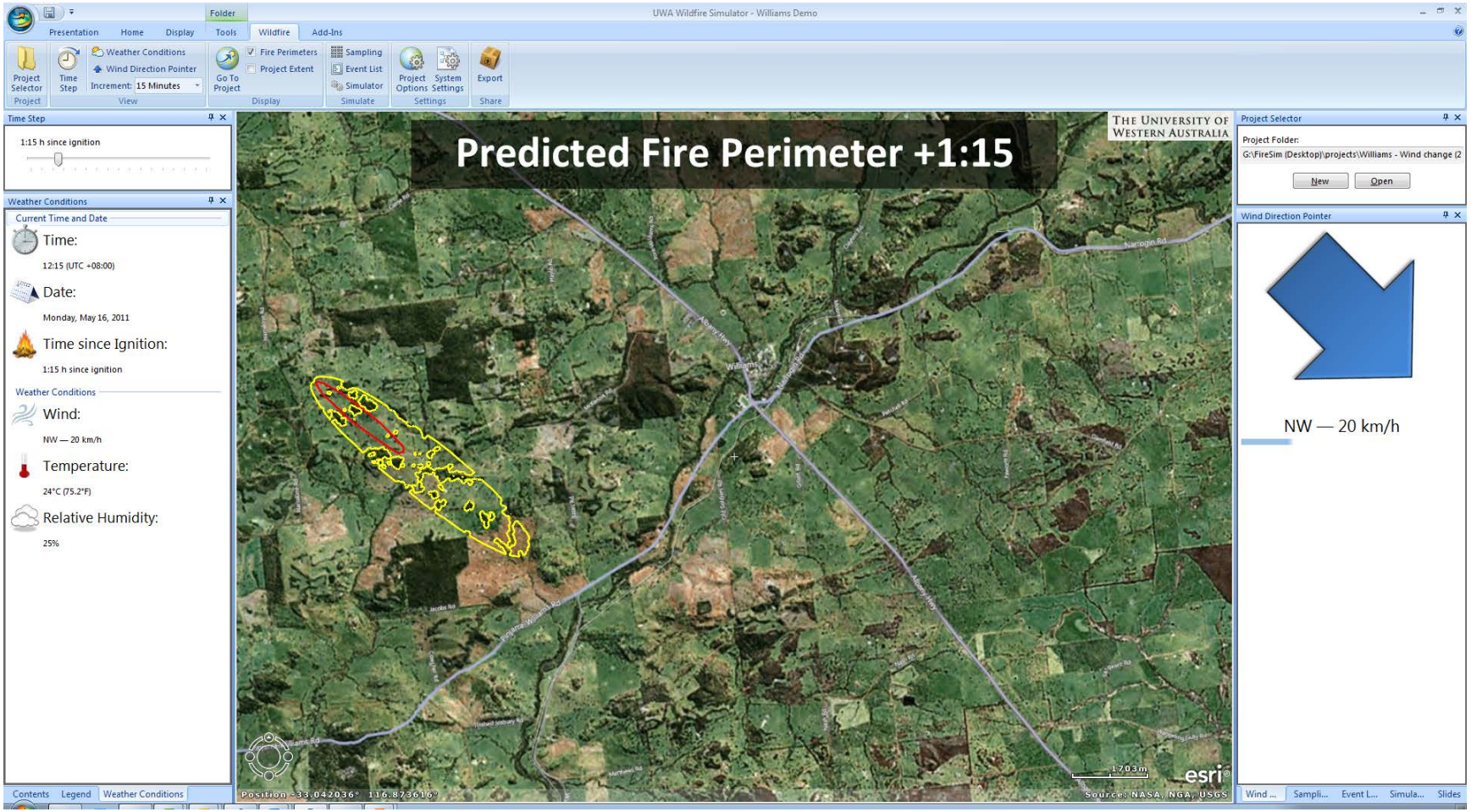
Source: USGS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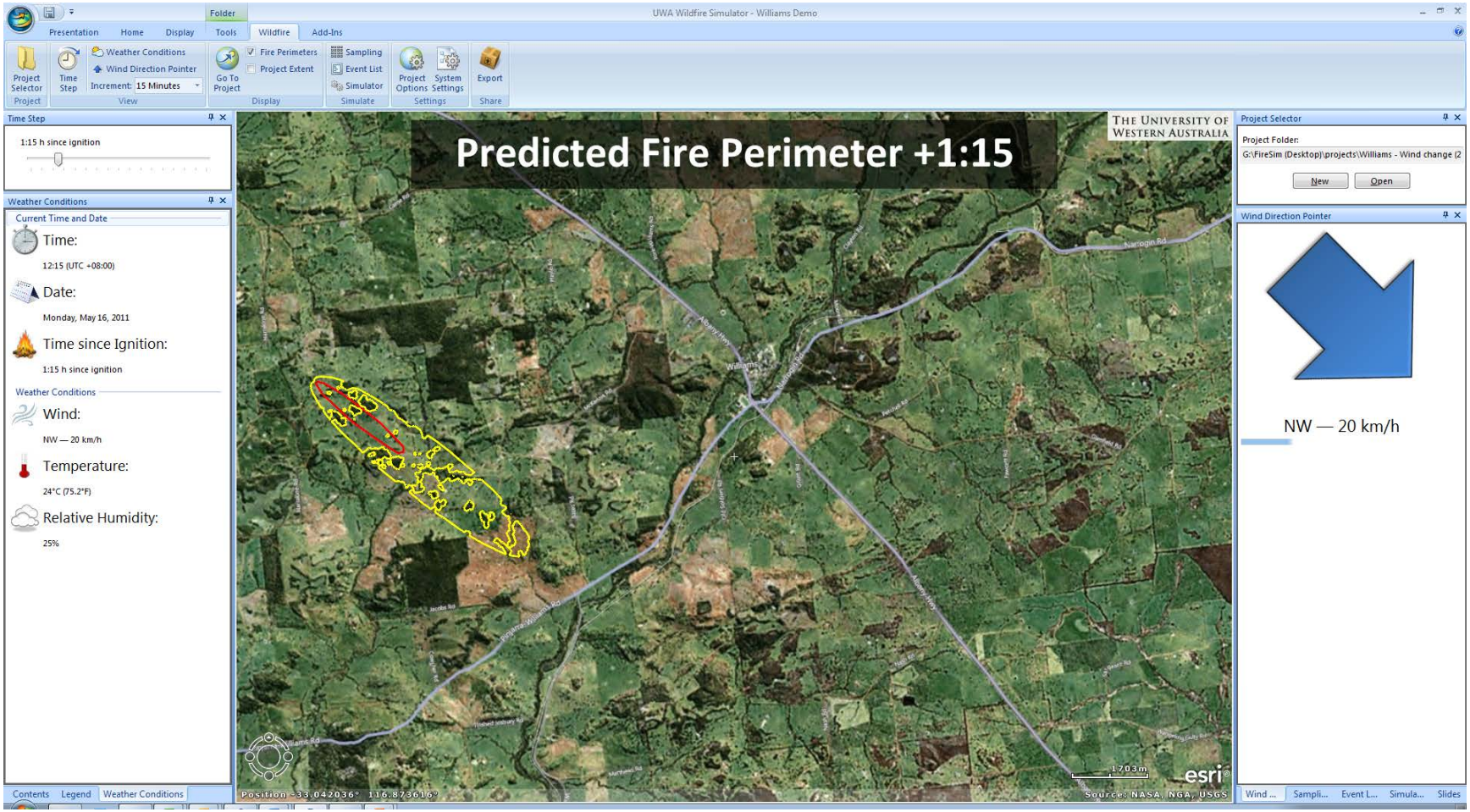
Source: NASA, NGA, USGS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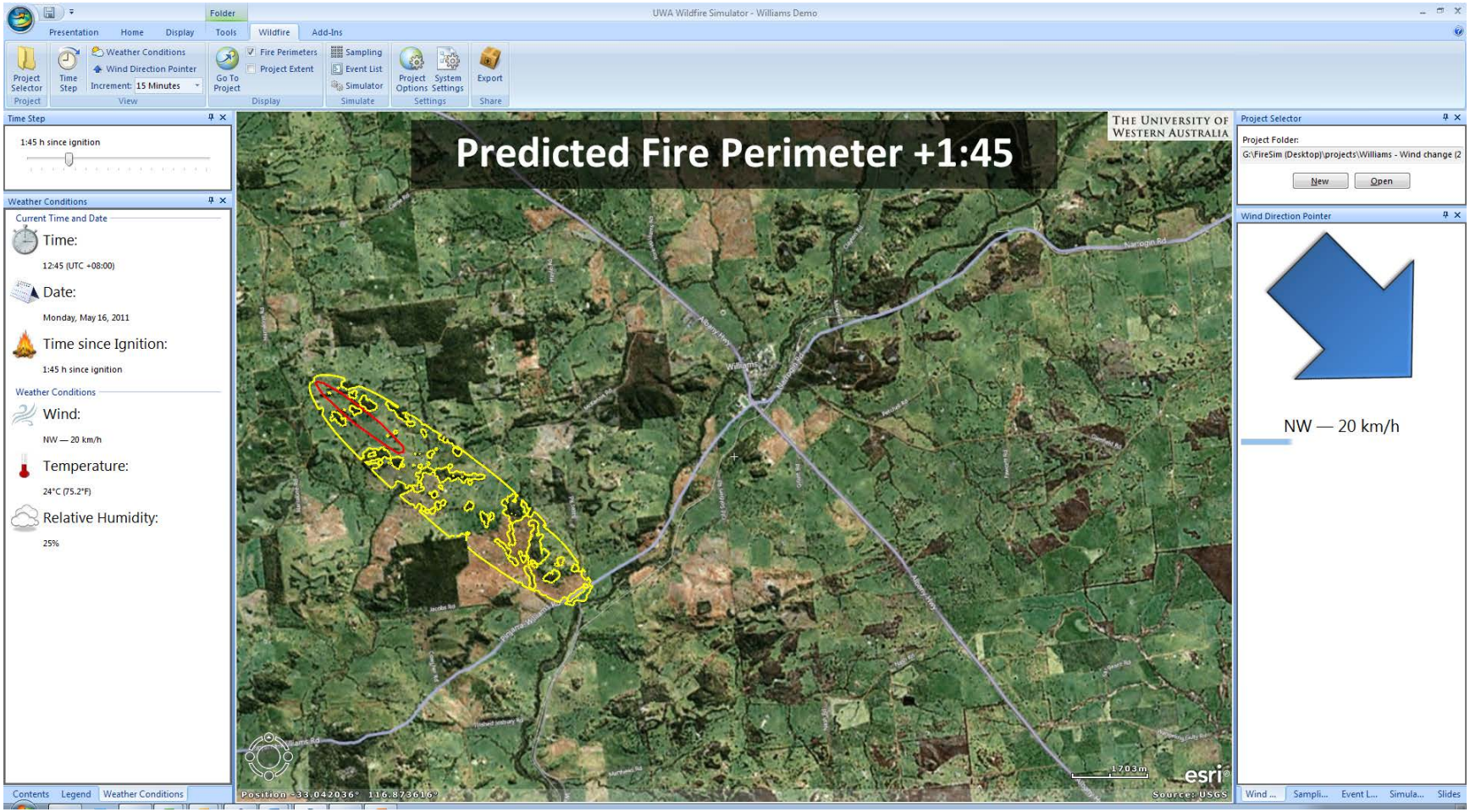
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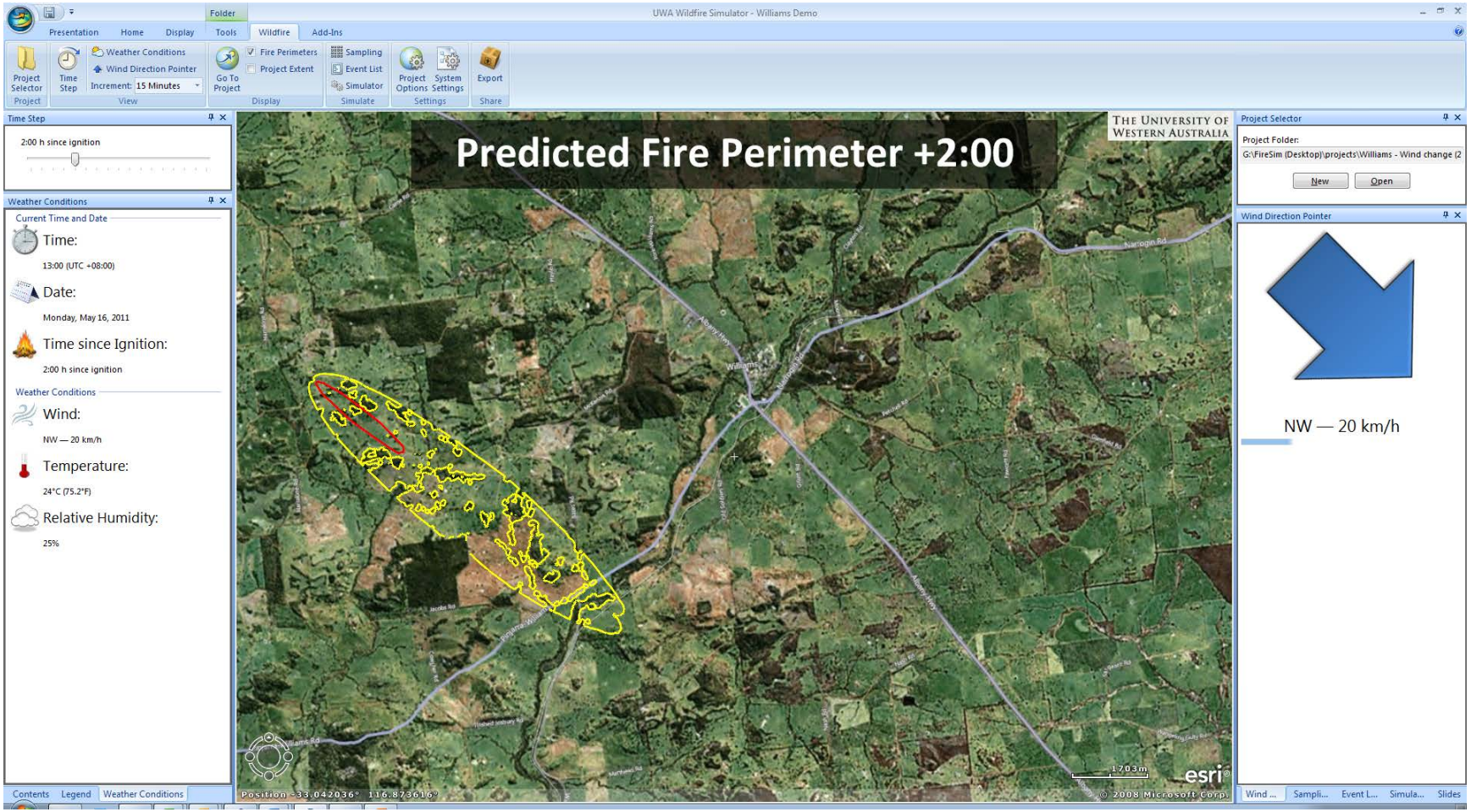
Position -33.042036° 116.873616°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Date:
Monday, May 16, 2011
Time since Ignition:
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Williams
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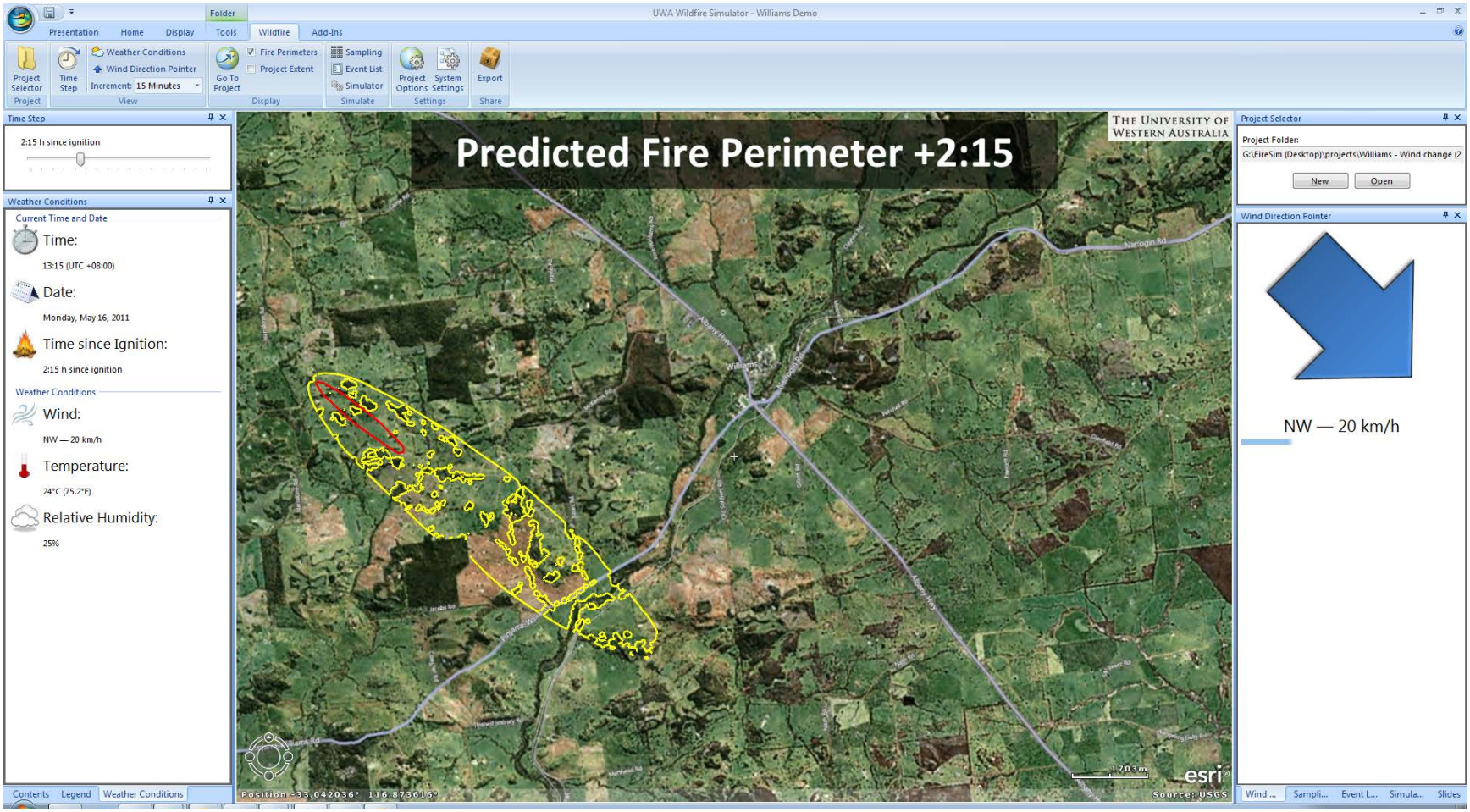
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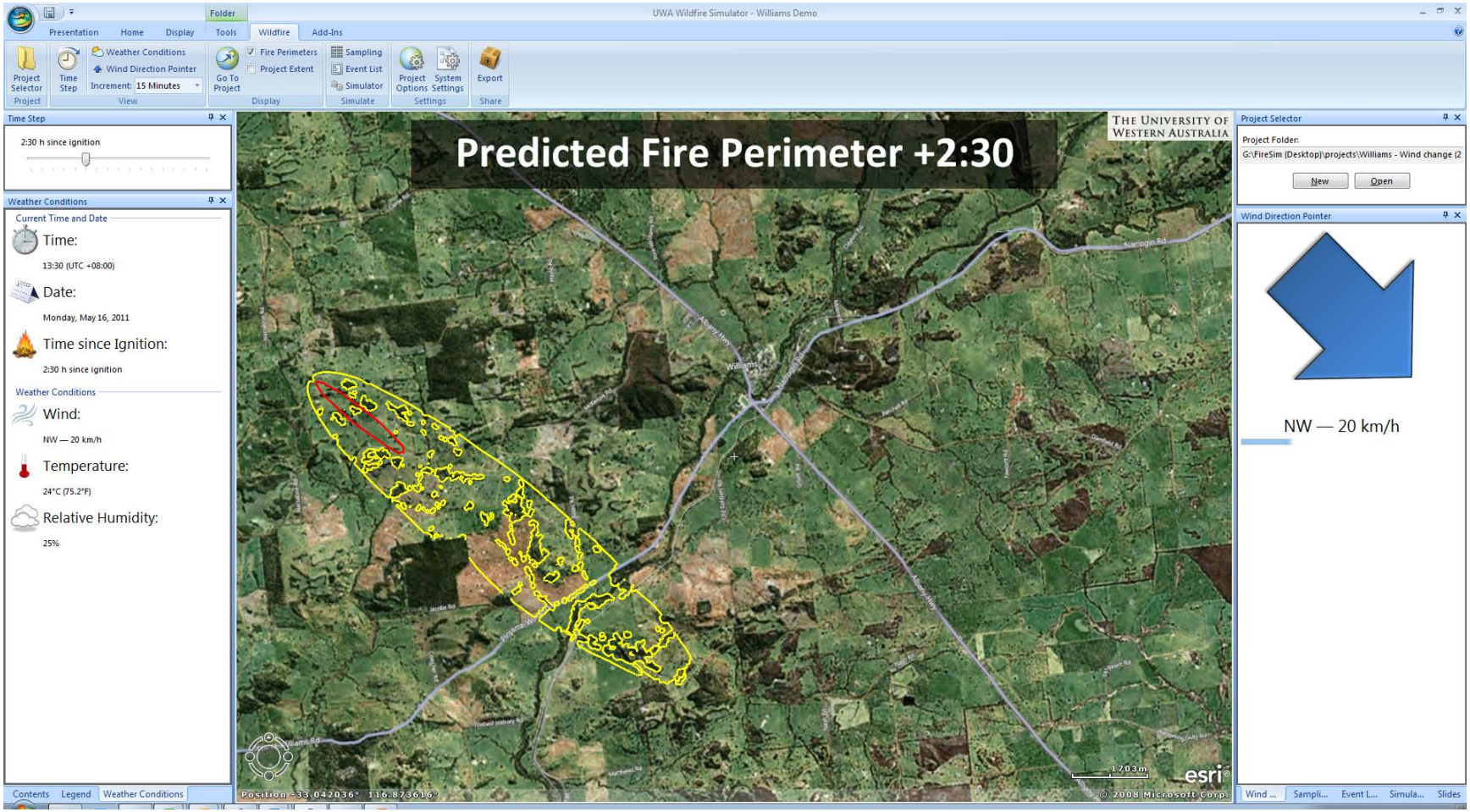
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Weather Conditions
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Date:
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Time since Ignition:
2:30 h since ignition
Weather Conditions
Wind:
NW — 20 km/h
Temperature:
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Relative Humidity:
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Position -33.042036° 116.873616°
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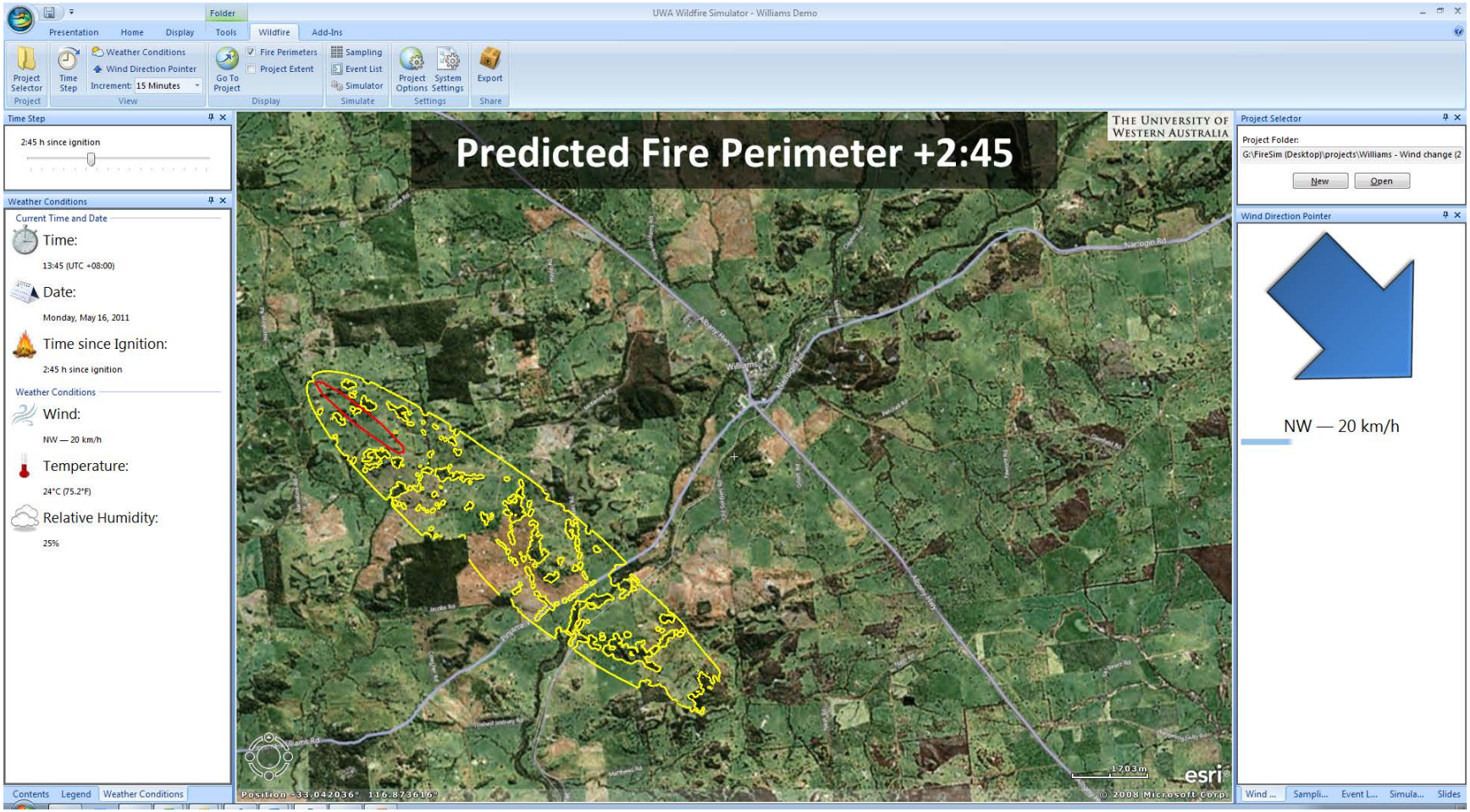
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Williams
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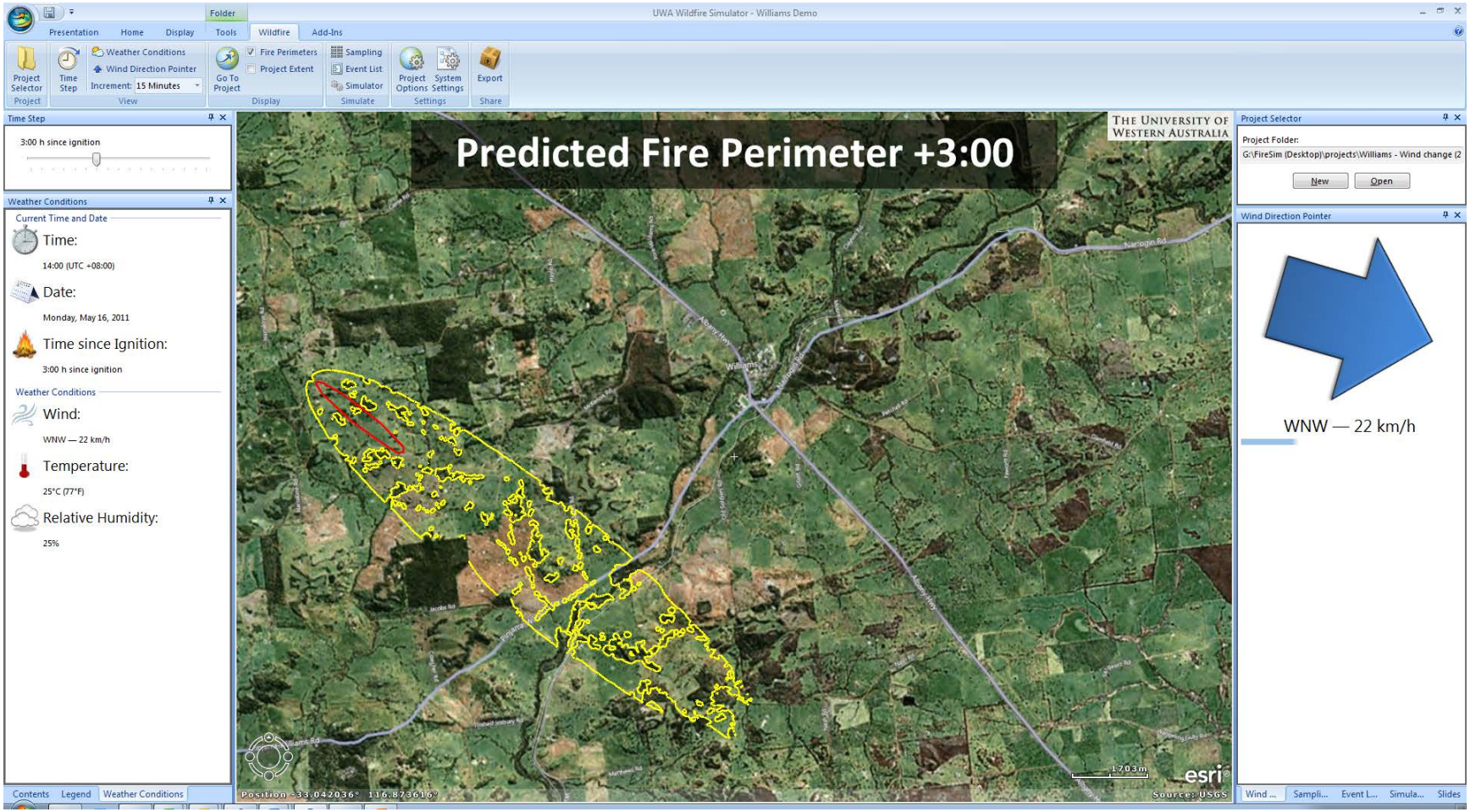
© 2008 Microsoft Corp.
Position -33.042036° 116.873616°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THE UNIVERSITY OF WESTERN AUSTRALIA
Time Step
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Time:
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Date:
Monday, May 16, 2011
Time since Ignition:
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WNW — 22 km/h
Temperature:
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Williams
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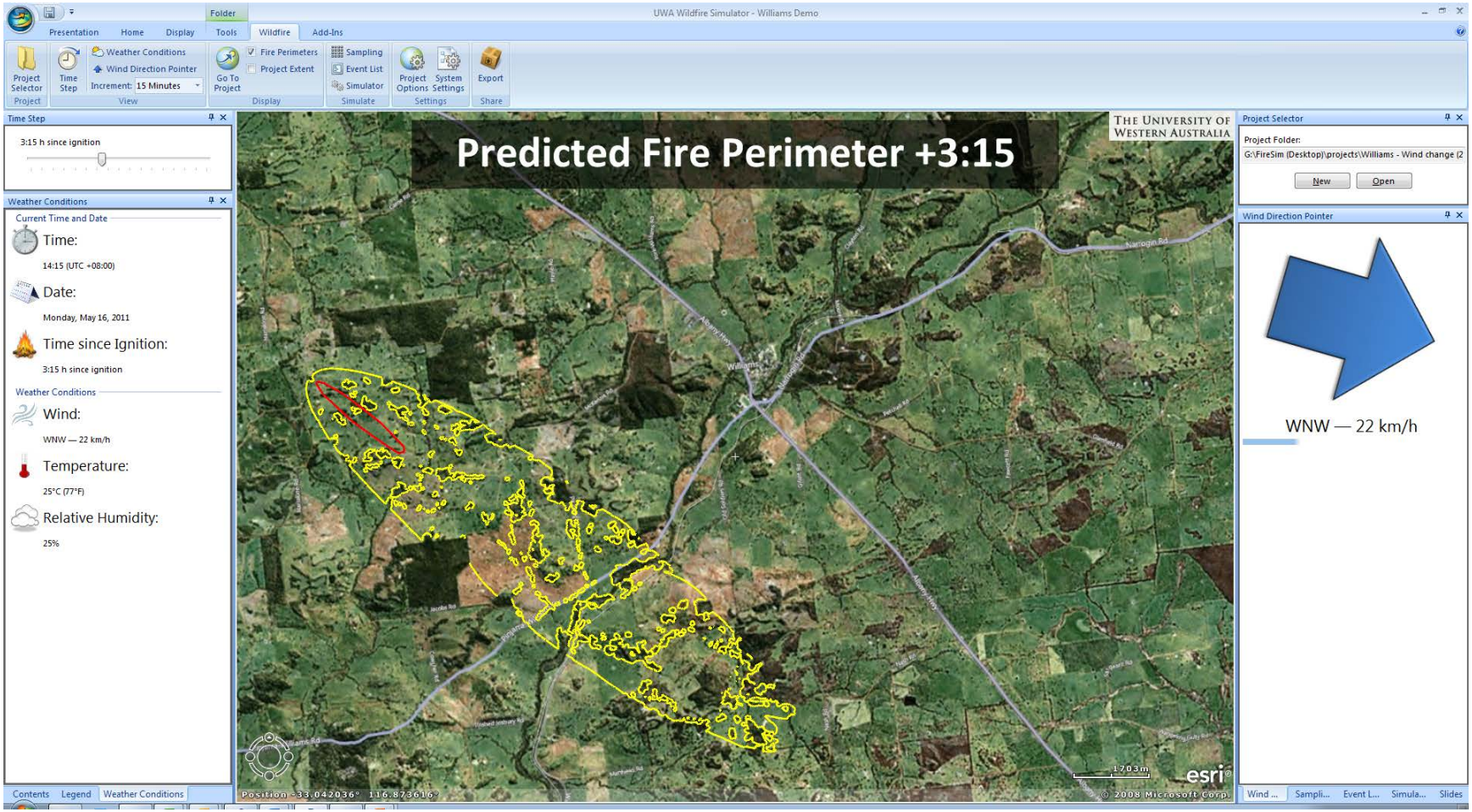
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Wind Direction Pointer
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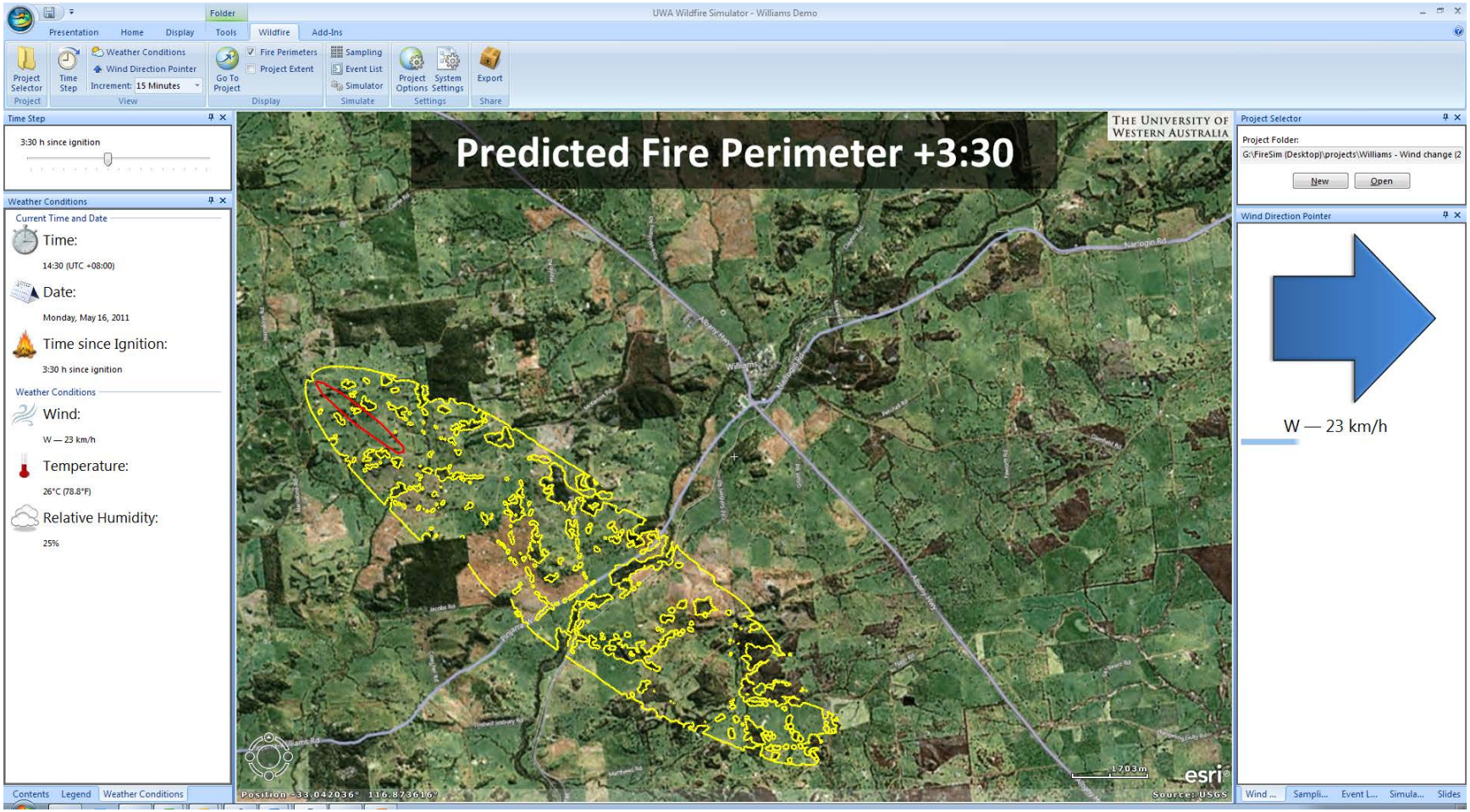
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Date:
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Time since Ignition:
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Weather Conditions
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Temperature:
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Relative Humidity:
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Source: USGS
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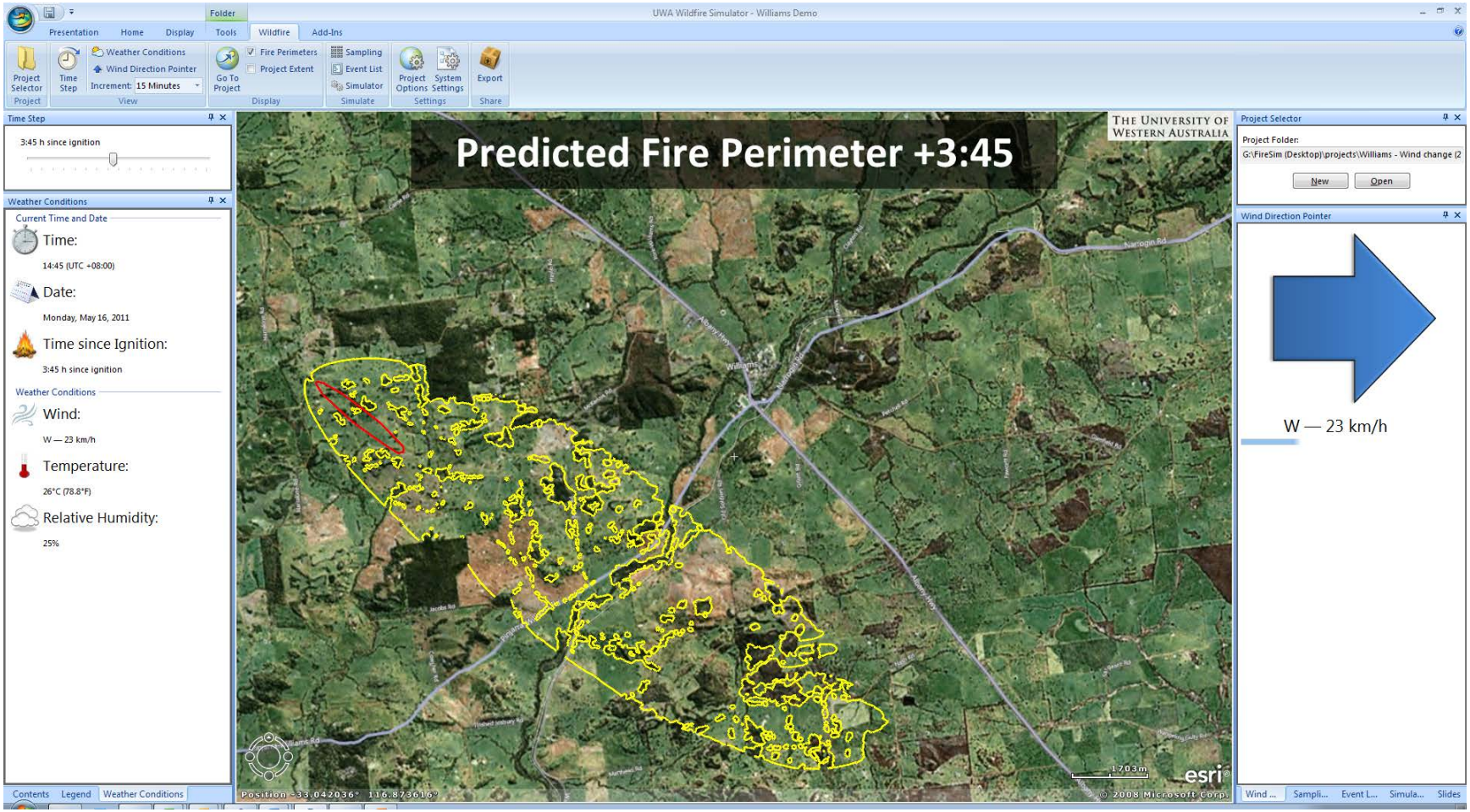
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THE UNIVERSITY OF WESTERN AUSTRALIA
Time Step
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Weather Conditions
Current Time and Date
Time:
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Time since Ignition:
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Project Selector
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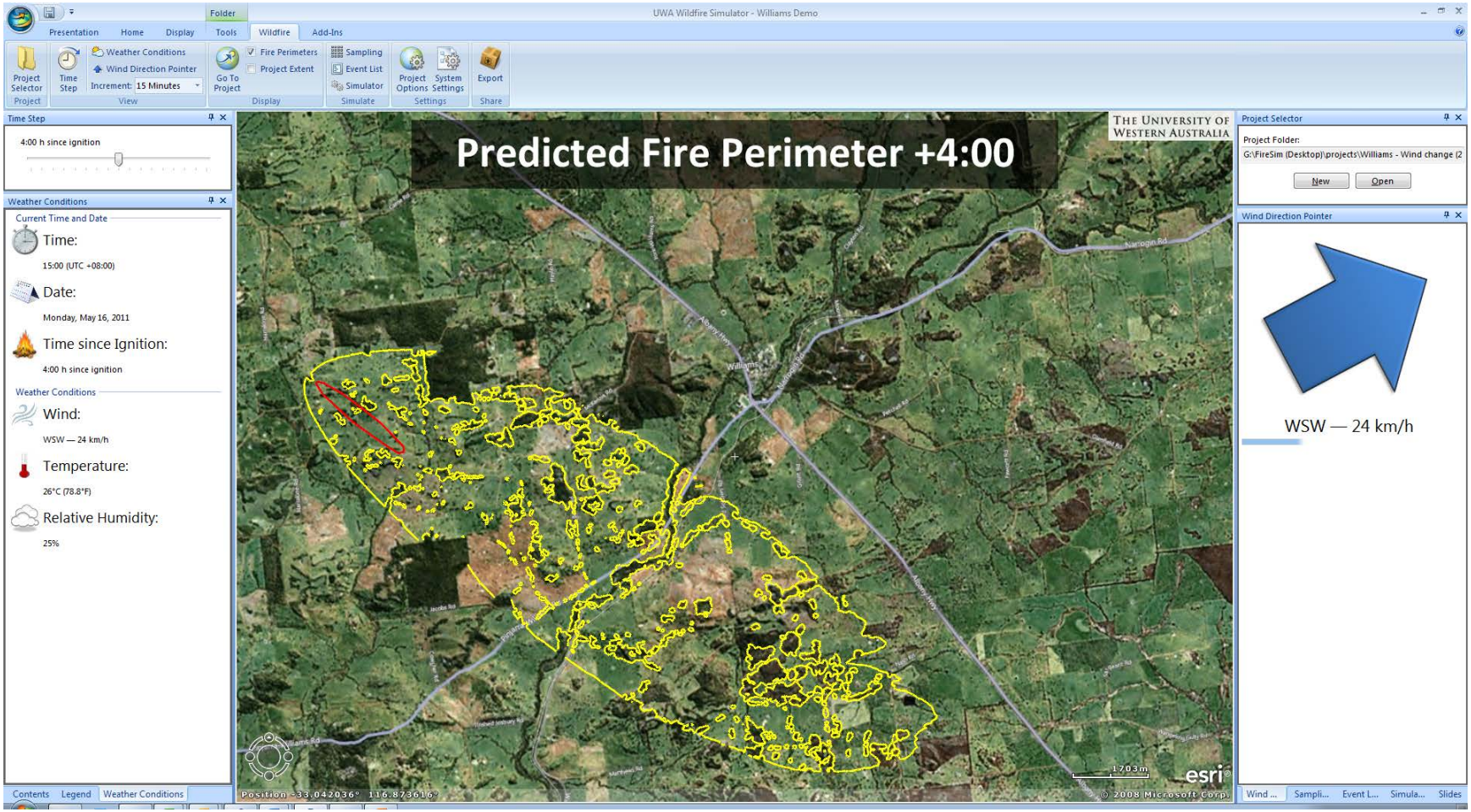
UWA Wildfire Simulator - Williams Demo
Predicted Fire Perimeter +4:00
THE UNIVERSITY OF WESTERN AUSTRALIA
Time Step
4:00 h since ignition
Weather Conditions
Current Time and Date
Time:
15:00 (UTC +08:00)
Date:
Monday, May 16, 2011
Time since Ignition:
4:00 h since ignition
Weather Conditions
Wind:
WSW — 24 km/h
Temperature:
26°C (78.8°F)
Relative Humidity:
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Project Selector
Project Folder:
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Wind Direction Pointer
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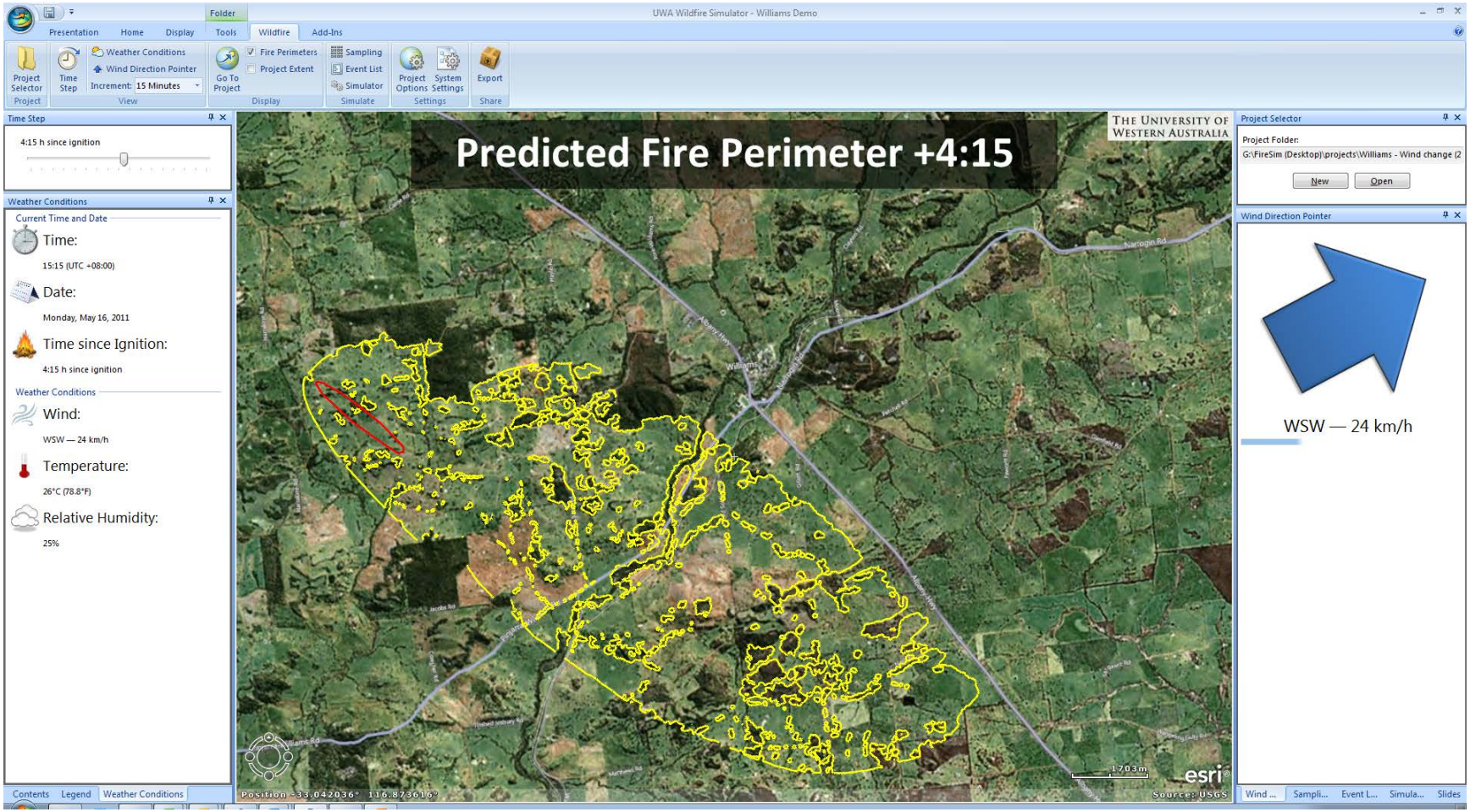
Position -33.042036° 116.873616°
© 2008 Microsoft Corp.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Predicted Fire Perimeter +4:15
THE UNIVERSITY OF WESTERN AUSTRALIA
Time Step
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Weather Conditions
Current Time and Date
Time:
15:15 (UTC +08:00)
Date:
Monday, May 16, 2011
Time since Ignition:
4:15 h since ignition
Weather Conditions
Wind:
WSW — 24 km/h
Temperature:
26°C (78.8°F)
Relative Humidity:
25%
Project Selector
Project Folder:
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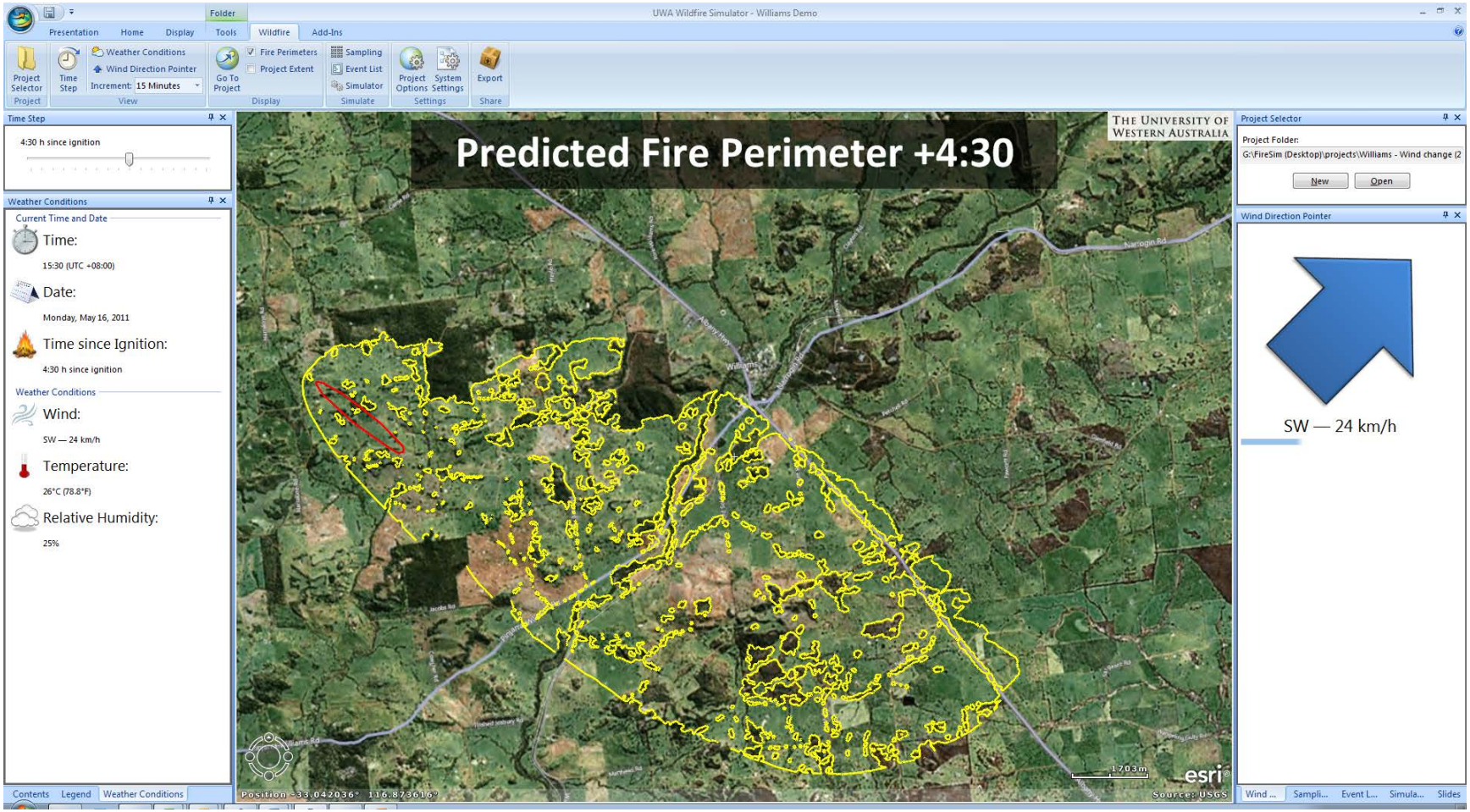
Open
Wind Direction Pointer
WSW — 24 km/h
Position -33.042036° 116.873616°
Source: USGS
esri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Time Step
4:30 h since ignition
Weather Conditions
Current Time and Date
Time:
15:30 (UTC +08:00)
Date:
Monday, May 16, 2011
Time since Ignition:
4:30 h since ignition
Weather Conditions
Wind:
SW — 24 km/h
Temperature:
26°C (78.8°F)
Relative Humidity:
25%
Project Selector
Project Folder:
New
Open
Wind Direction Pointer
SW — 24 km/h
Position -33.042036° 116.873616°
Source: USGS
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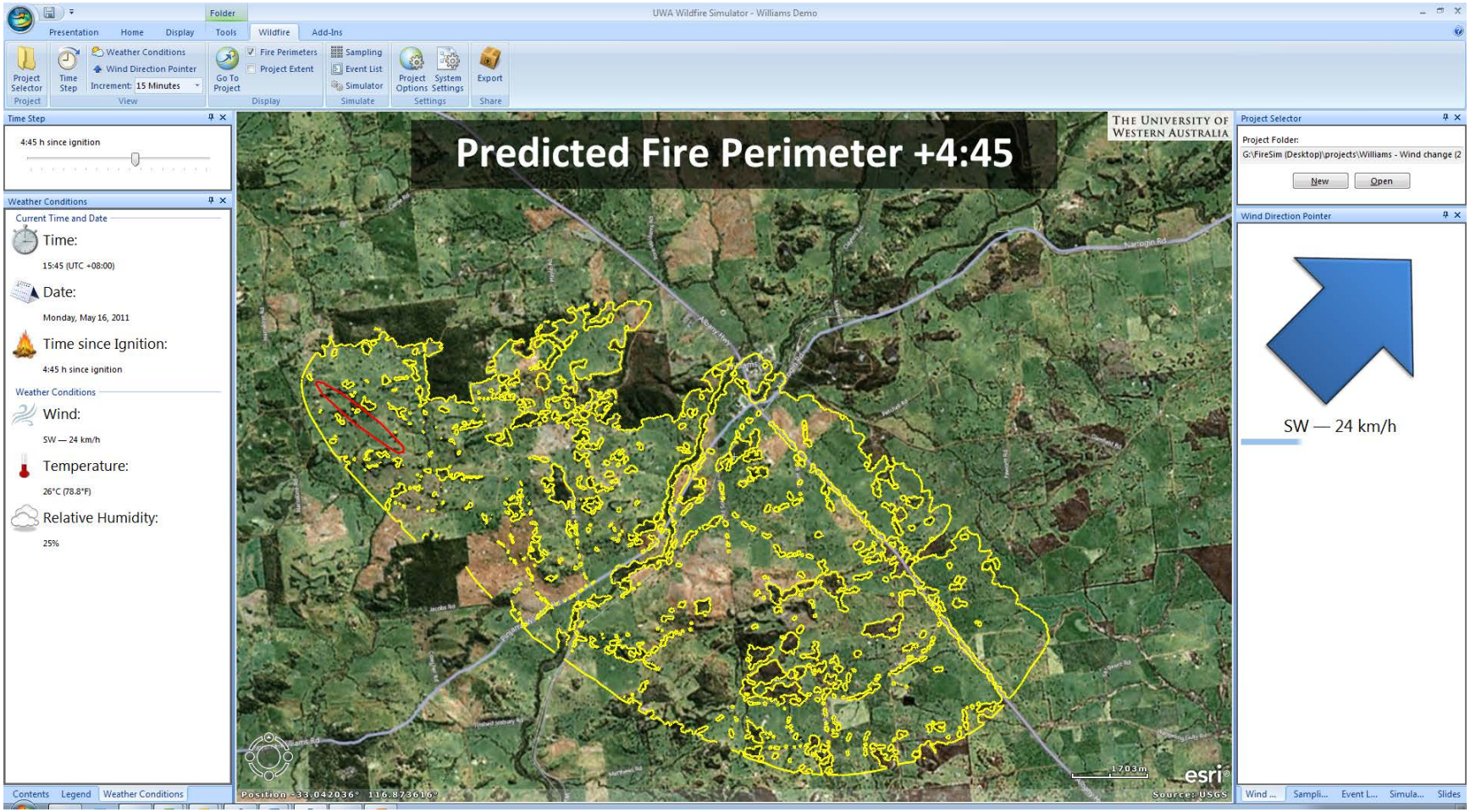
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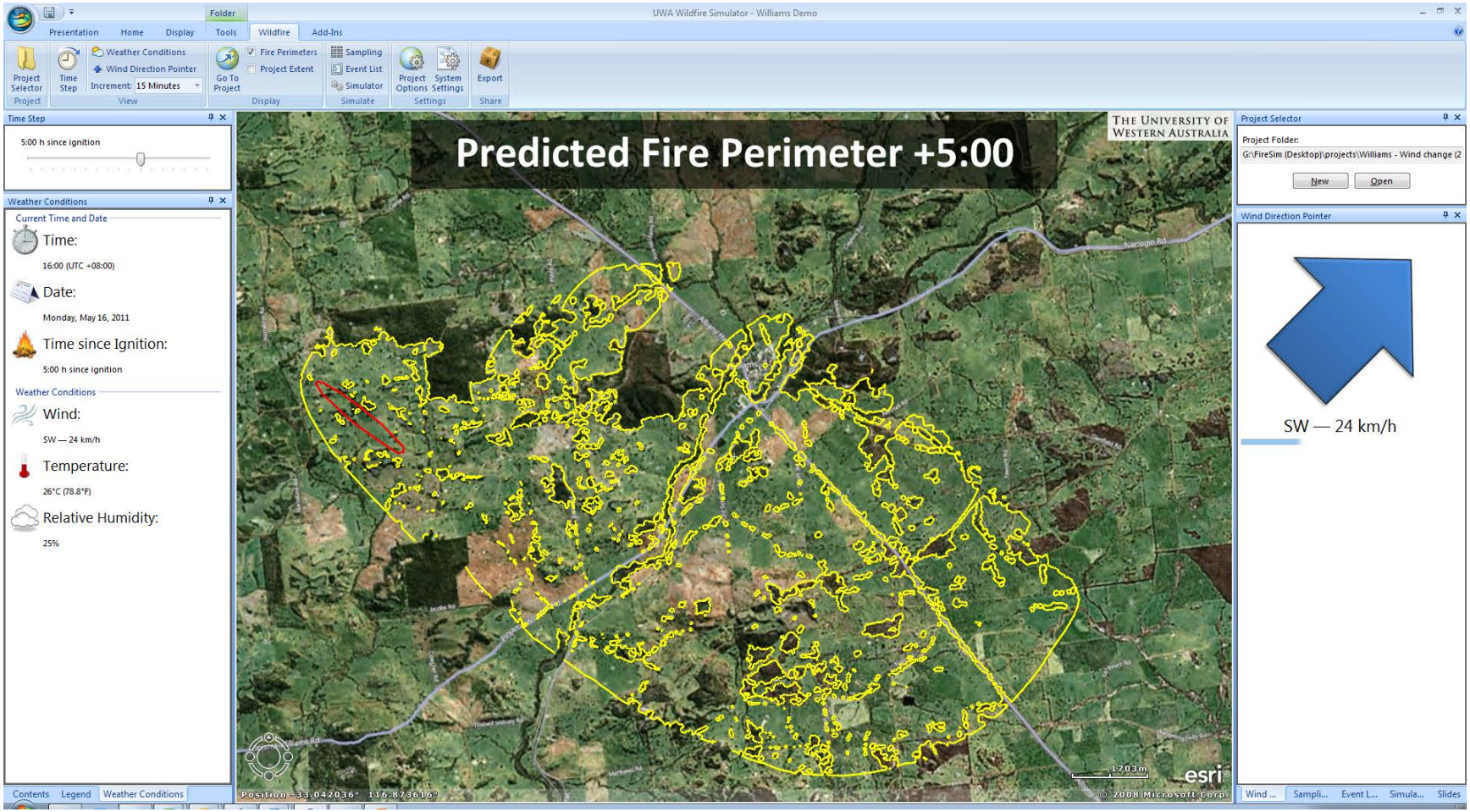
4:45 h since ignition
Weather Conditions
Current Time and Date
Time:
15:45 (UTC +08:00)
Date:
Monday, May 16, 2011
Time since Ignition:
4:45 h since ignition
Weather Conditions
Wind:
SW — 24 km/h
Temperature:
26°C (78.8°F)
Relative Humidity:
25%
Project Selector
Project Folder:
New
Open
Wind Direction Pointer
SW — 24 km/h
Narrogin Rd
1703m
esri
Source: USGS


UWA Wildfire Simulator - Williams Demo
Predicted Fire Perimeter +5:00
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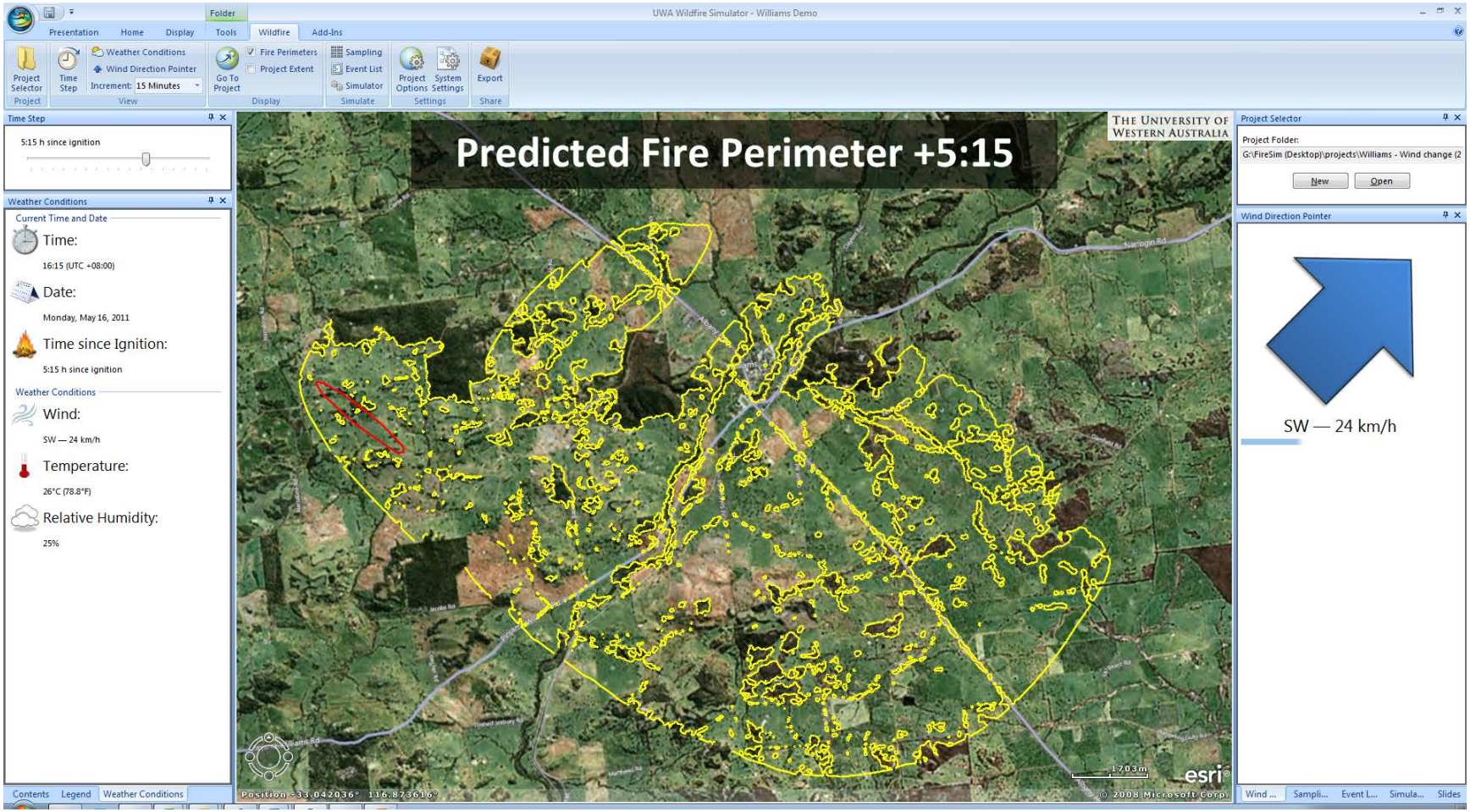
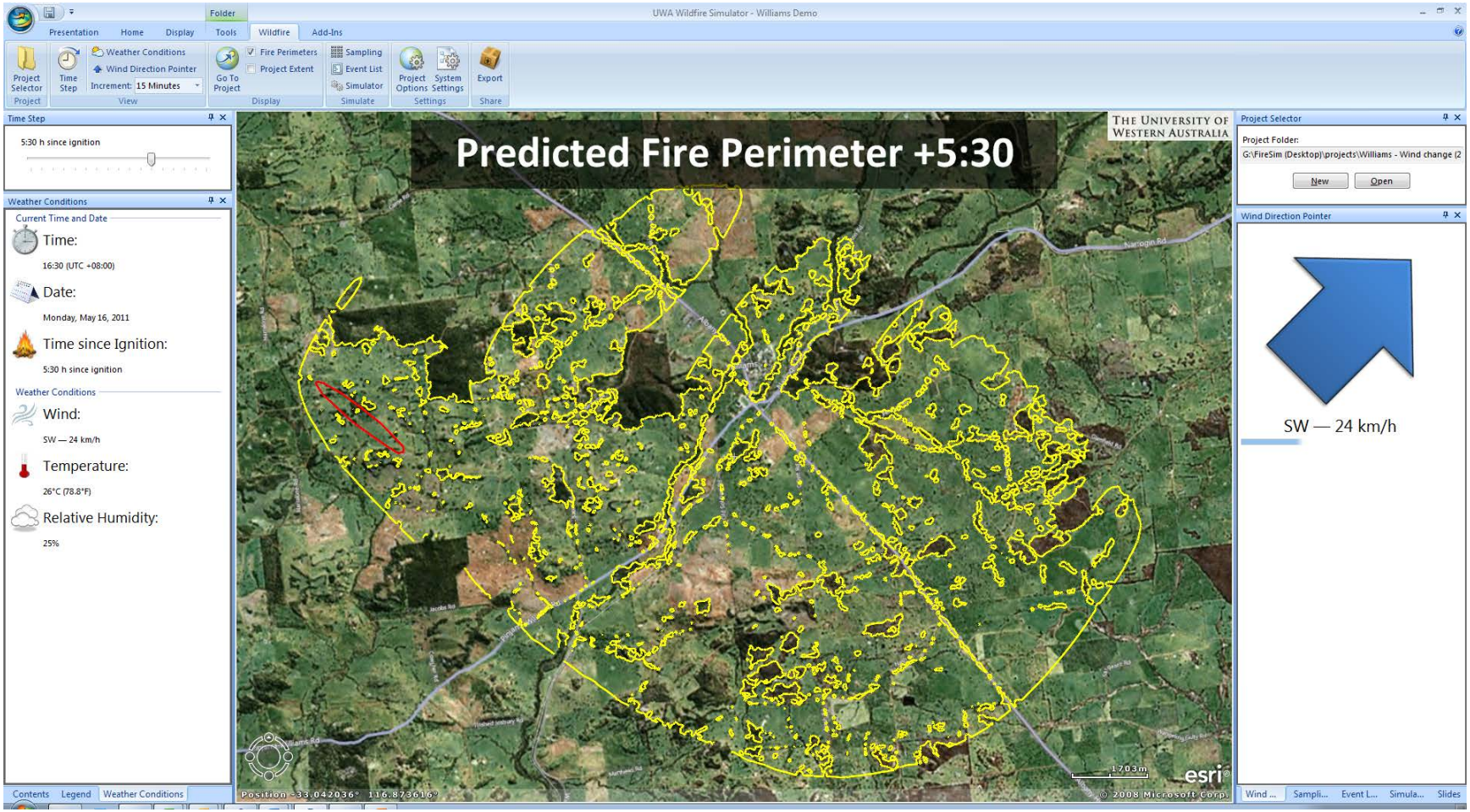
Time Step
5:00 h since ignition
Weather Conditions
Current Time and Date
Time:
16:00 (UTC +08:00)
Date:
Monday, May 16, 2011
Time since Ignition:
5:00 h since ignition
Weather Conditions
Wind:
SW — 24 km/h
Temperature:
26°C (78.8°F)
Relative Humidity:
25%
Project Selector
Project Folder:
New
Open
Wind Direction Pointer
SW — 24 km/h
Position -33.042036° 116.873616°
© 2008 Microsoft Corp.


UWA Wildfire Simulator - Williams Demo
Predicted Fire Perimeter +5:15
THE UNIVERSITY OF WESTERN AUSTRALIA
Time Step
5:15 h since ignition
Weather Conditions
Current Time and Date
Time:
16:15 (UTC +08:00)
Date:
Monday, May 16, 2011
Time since Ignition:
5:15 h since ignition
Weather Conditions
Wind:
SW — 24 km/h
Temperature:
26°C (78.8°F)
Relative Humidity:
25%
Project Selector
Project Folder:
New
Open
Wind Direction Pointer
SW — 24 km/h
1703m
esri
© 2008 Microsoft Corp.


UWA Wildfire Simulator - Williams Demo
Predicted Fire Perimeter +5:30
THE UNIVERSITY OF WESTERN AUSTRALIA
Time Step
5:30 h since ignition
Weather Conditions
Current Time and Date
Time:
16:30 (UTC +08:00)
Date:
Monday, May 16, 2011
Time since Ignition:
5:30 h since ignition
Weather Conditions
Wind:
SW — 24 km/h
Temperature:
26°C (78.8°F)
Relative Humidity:
25%
Project Selector
Project Folder:
New
Open
Wind Direction Pointer
SW — 24 km/h
Position -33.042036° 116.873616°
© 2008 Microsoft Corp.
esri

Data sets required prior to operation

Pre-loaded:

- topographic maps
- vegetation maps
- fuel load maps
- rate-of-spread model for each vegetation type

For specific fires:

- current and forecast weather – downloaded automatically from Bureau of Meteorology
- ignition locations and time of ignition (or current fire perimeter) – entered manually into GIS

AUSTRALIS Simulator: validation using historical fires

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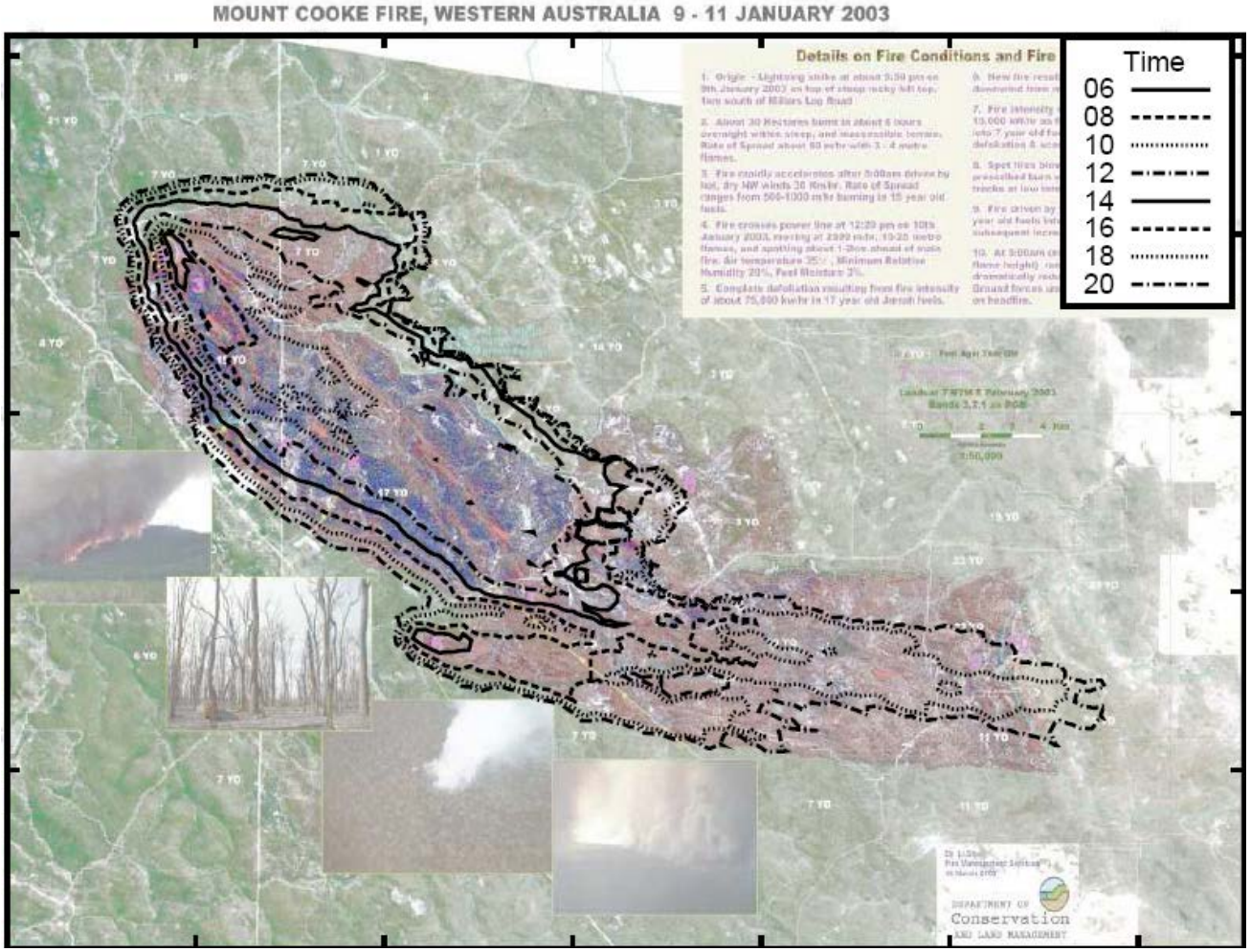
Mt Cooke fire simulation with different fuel ages resulting from previous fuel reduction burns

(base map by Lachie McCaw Dept of Parks & Wildlife, WA)



Same scenario with no previous fuel reduction

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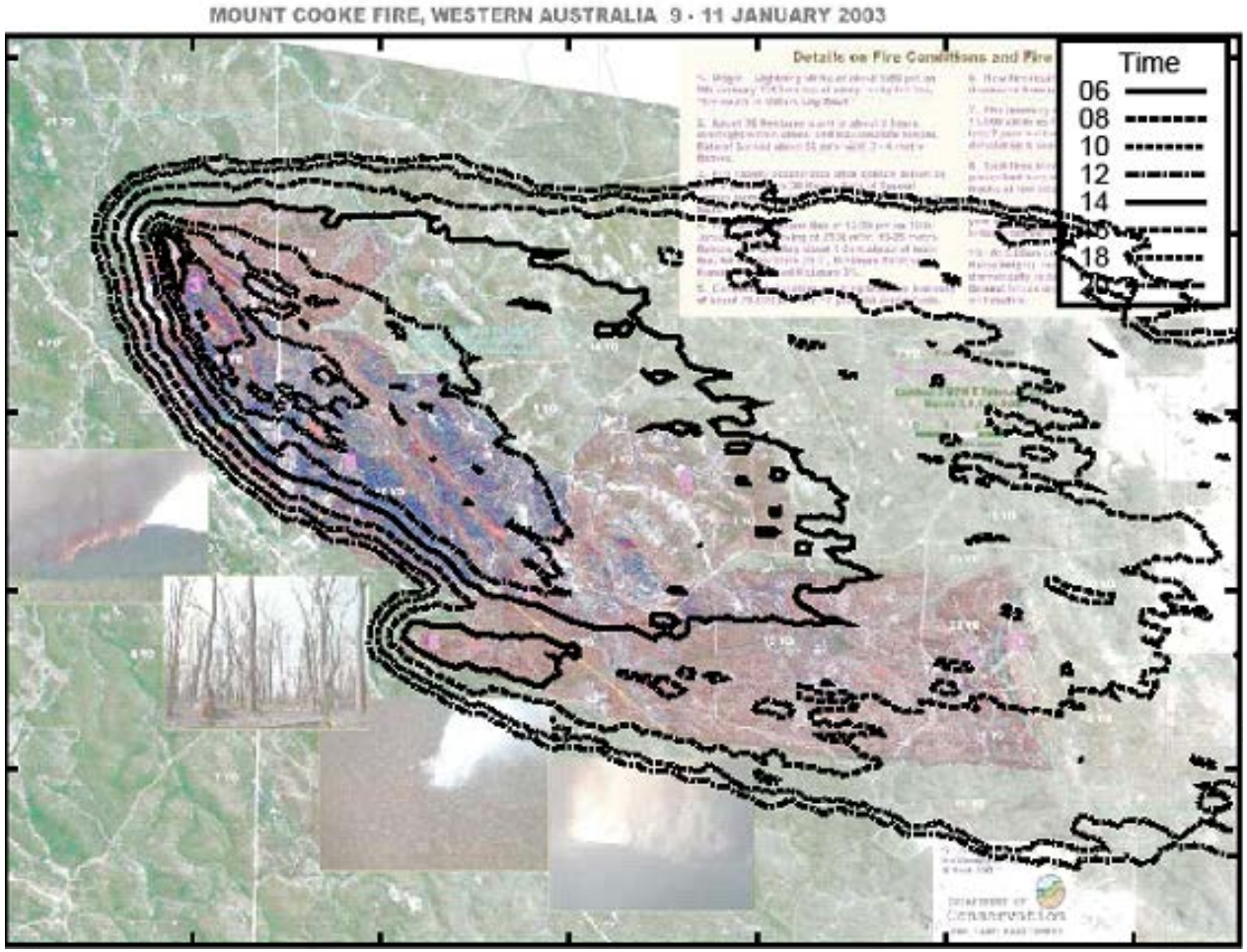
Mt Cooke fire simulation assuming all areas have 15 year old fuel



Validation Technique

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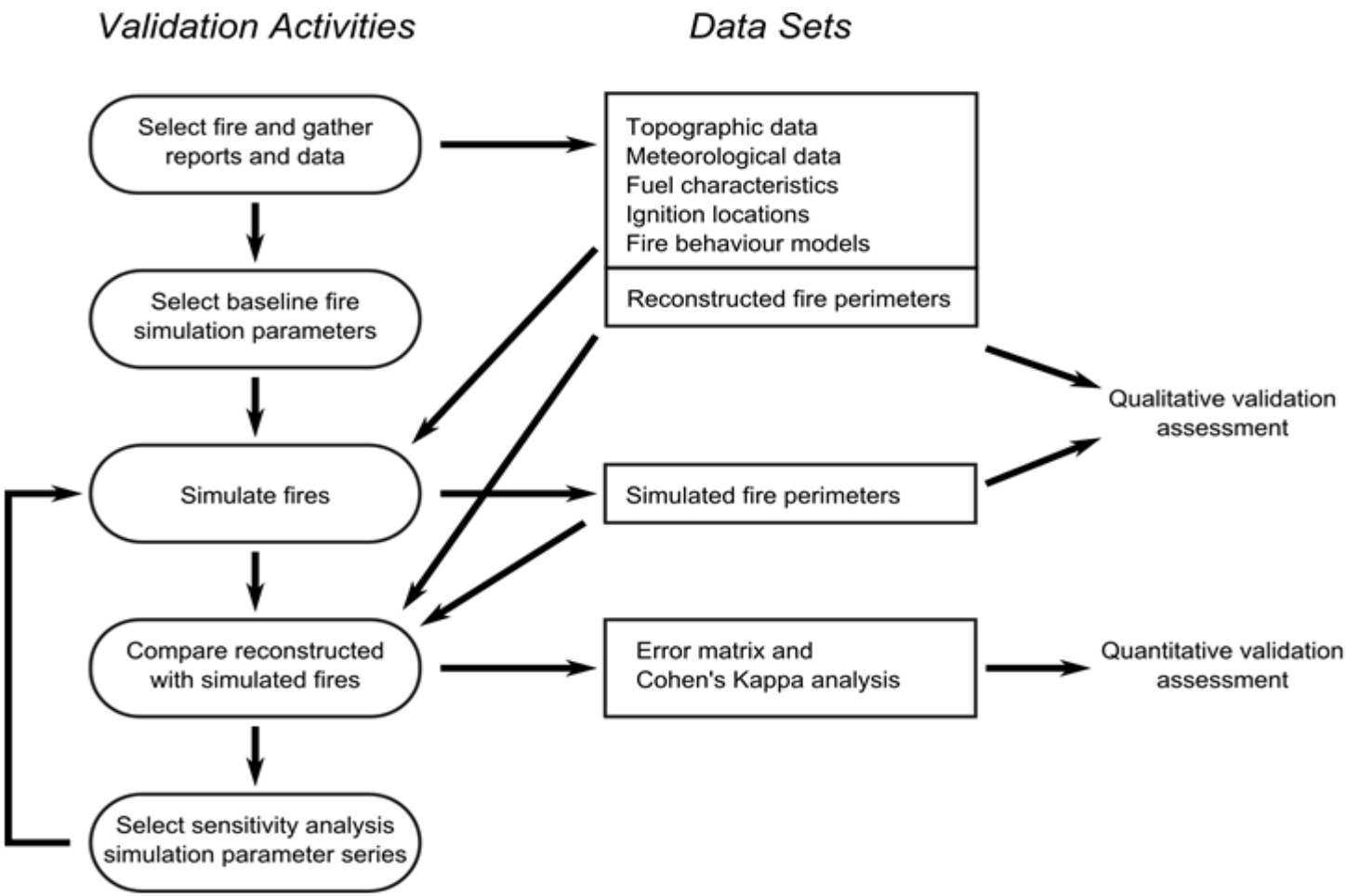

Overview of fire-spread simulator validation technique

Simulating the Boorabbin Fire, WA

- *Fire progression perimeters* reconstructed at high spatial and temporal resolution[A]
- *Simulation inputs* obtained from coronial reports into meteorological conditions[B] and fire development chronology[A]
- Simulations used to investigate the accuracy of *rate-of-spread meters*, the effect of *length-to-breadth ratios* and *key sources of inaccuracy* (e.g. wind direction and vegetation map)
- Four phases were independently simulated: 1, 2, 3A and 3B

[A] Goldfields Fire 13 (Boorabbin Fire): Fire Development Chronology, GHD Pty Ltd, P. de Mar (2008)
[B] Meteorological aspects of the Boorabbin fire: 28 December 2007 – 8 January 2008, Bureau of Meteorology (2008)

Spatial extent of the Boorabbin Fire (28-30 December 2007)

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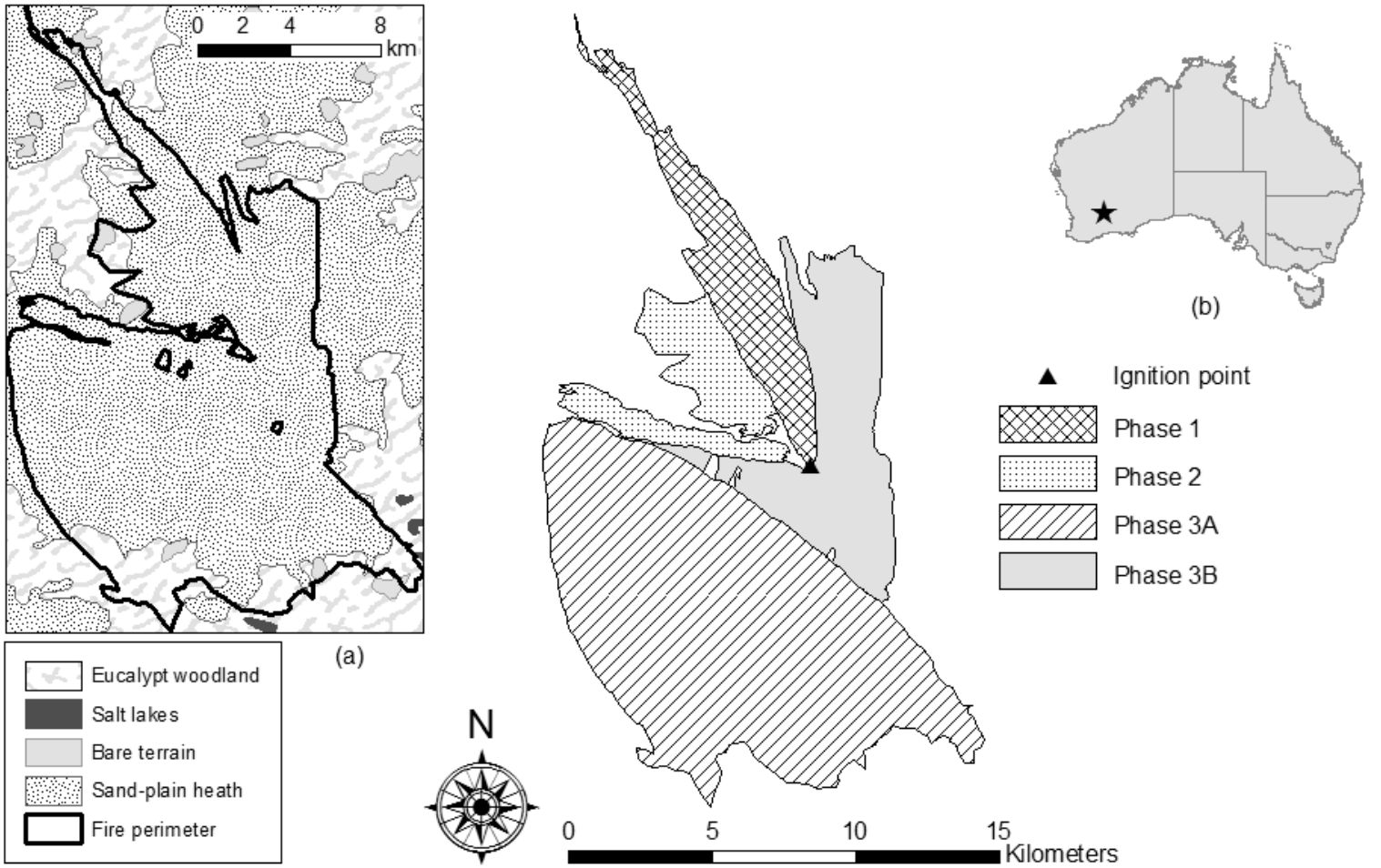

Geo-referenced perimeters of the Boorabbin fire supplied by the Department of Environment and Conservation, Western Australia (DEC) and P. de Mar (GHD Pty Ltd)

Vegetation communities

Sand-plain heath

Note: non-continuous fuels

Eucalypt woodland
(predominantly Salmon gum)

Meteorological conditions at Southern Cross AWS (~75 km W)

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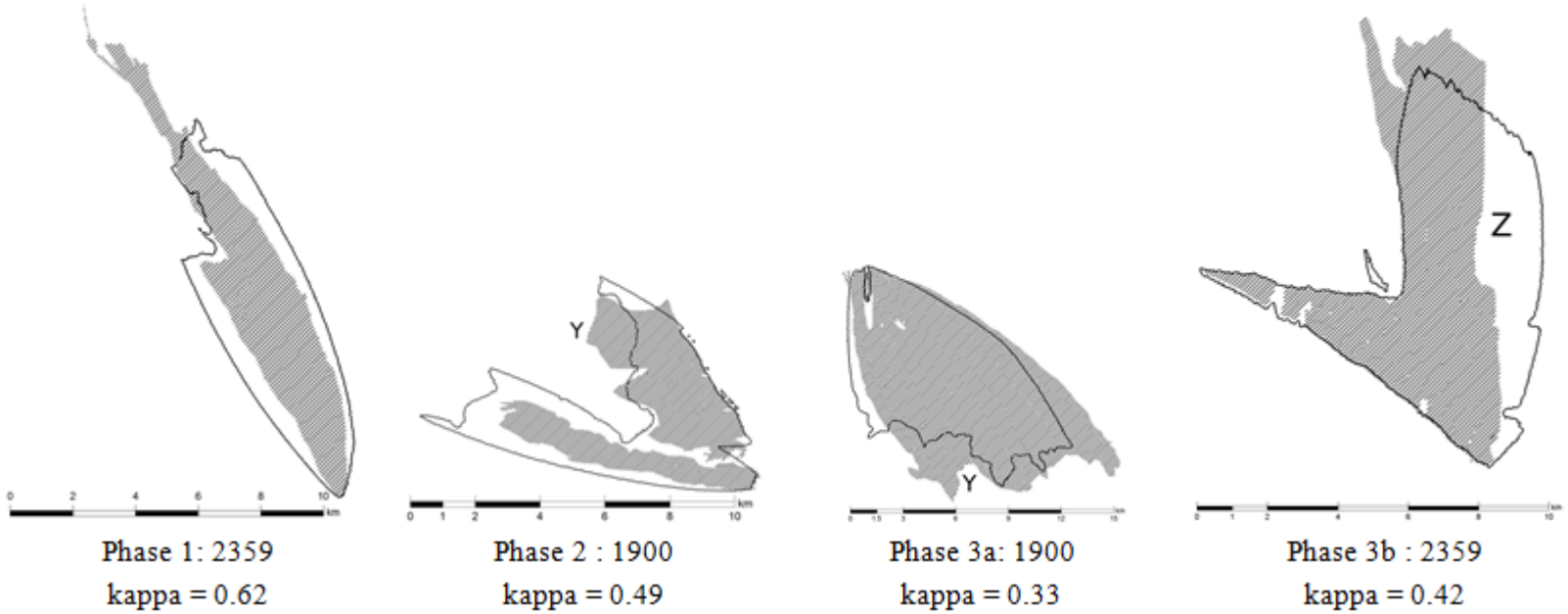
	Phase 1	Phase 2	Phase 3A	Phase 3B
Time (WDT; UTC+9)	1200–2400	1100–1900	1100–2000	2000–2400
Date	28 December 2007	29 December 2007	30 December 2007	30 December 2007
Area burned[A] (ha)	2,200	1,950	10,000	3,700
Meteorological conditions[B]				
Temperature (°C)	19–37 (31)	25–35 (32)	38–43 (42)	20–38 (28)
Relative humidity (%)	19–58 (30)	18–36 (24)	4–11 (7)	9–68 (41)
Wind speed (km h^{-1})	18–39 (27)	19–24 (21)	22–44 (34)	26–48 (37)
Fire weather severity[B]				
Fire Danger Index (FDI)	28	20	104	47
Fire Danger Rating (FDR)	Very High	High	Extreme+	Extreme

Source: [A] (de Mar 2008); [B] Southern Cross AWS (Bureau of Meteorology 2008)

Final fire perimeters for each phase



Final fire perimeters estimated by the reconstruction report (shaded) and simulated by* AUSTRALIS *(black line) at the end of each phase. The agreement statistic kappa is given for each phase, which takes into account agreement between intermediate estimated and simulated fire perimeters (not shown). Spread under-predictions in Phase 2 and 3a marked Y are due to vegetation mapping inaccuracies; spread over-prediction in Phase 3b (marked Z) is due to weather data inaccuracy.

Accuracy of simulated perimeters (Phases 1 & 2)

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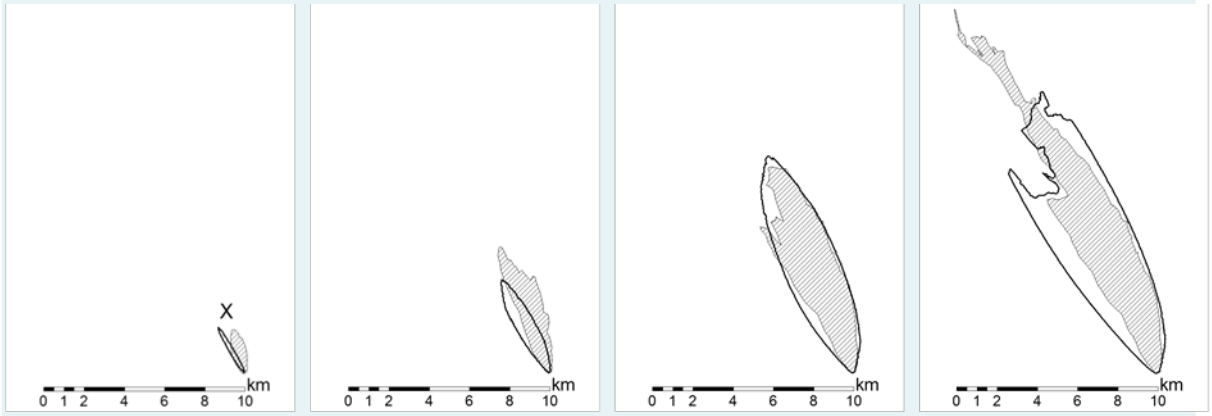
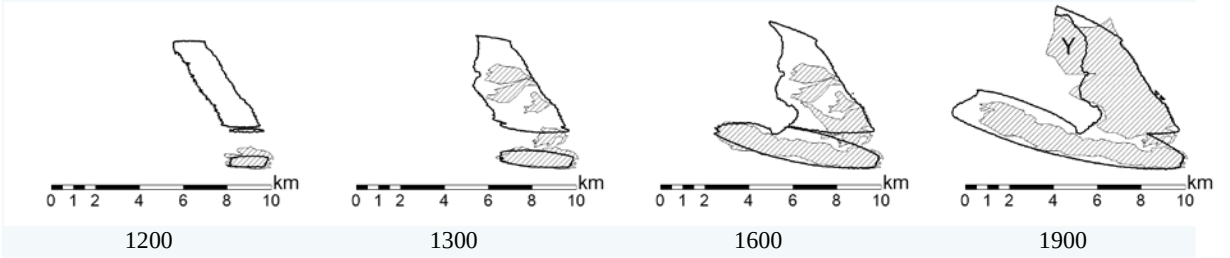
	Accuracy	Simulations (semi-arid heath meter)
Phase 1	K = 0.62	 1500 1700 2030 2359
Phase 2	K = 0.52	 1200 1300 1600 1900
		

Accuracy of simulated perimeters (Phases 3A & 3B)

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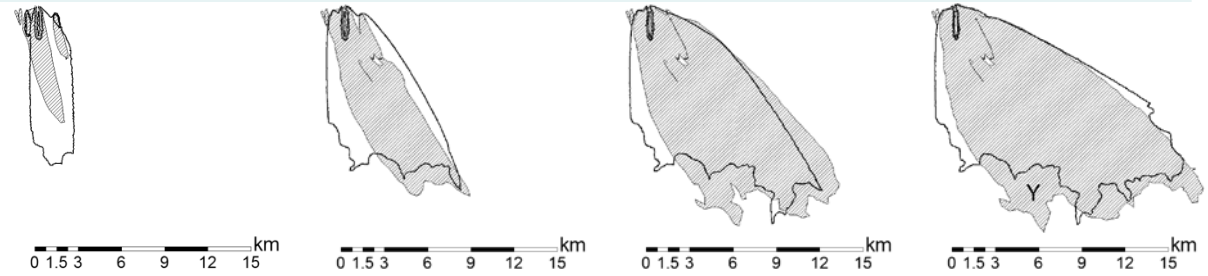
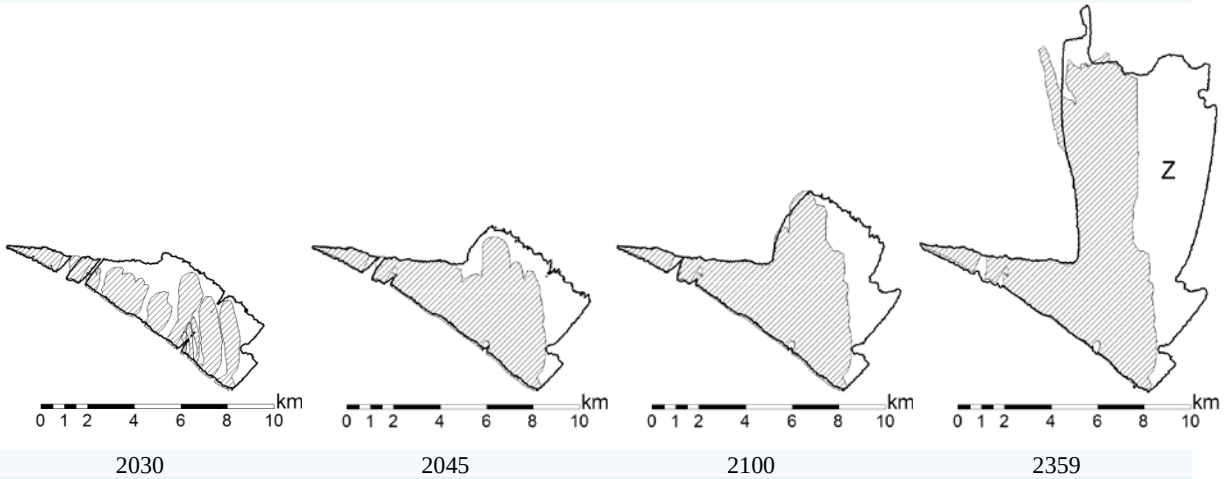
	Accuracy	Simulations (semi-arid heath meter)
Phase 3A	K = 0.57	
Phase 3B	K = 0.56	

Correcting for inaccuracy in wind direction

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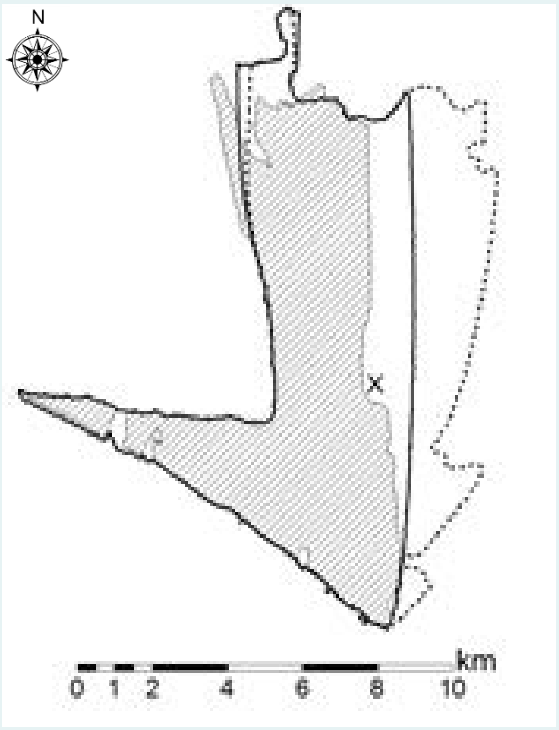
Wind direction

Time (WDT)	Wind direction (°)	
	Observed at S. Cross AWS[A]	Inferred from reconstruction[B]
2000	219	215
2030	210	180
2100	185	180
2200	182	180
2300	174	174
2359	172	172

[A] (Bureau of Meteorology 2008) [B] (de Mar 2008)

Wind direction	Accuracy (K)
Observed	0.56
Inferred	0.66

Simulations



Inferred Observed Reconstructed

Sensitivity Analysis

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Simulation parameters and models	Baseline value/model	Sensitivity analysis range
Cell grid		
Cell size (m)	50	50, 100, 250, 500, 750 5 randomly generated grids at each size.
Meteorological variables		
Wind speed measured at 10 m (km/h)	Southern Cross AWS (U10)	U10 ± 5, U10 ± 10, U10 ± 15, U10 ± 20
Wind direction (°)	As above (WD)	WD ± 5, WD ± 10, WD ± 15
Temperature (°C)	As above (T)	T ± 5, T ± 10, T ± 15
Relative Humidity (%)	As above (RH)	RH ± 5, RH ± 10, RH ± 15
Fuel variables		
PCS of elevated fuel layer (0–4)	1.5	1, 1.5, 2, 2.5, 3, 3.5, 4
Fire behaviour models		
Fire behaviour model for heath vegetation	HE	HE, MH1, MH2, MH3, SH, HG

Simulation parameters varied in sensitivity analysis simulations and the series of parameter values examined for each. Abbreviations are as follows. AWS – automatic weather station; U10 – 10 m wind speed recorded at the Southern Cross AWS; WD – wind direction (degrees clockwise from North); WS – wind speed (kilometres per hour); T – temperature (degrees Celsius); RH – relative humidity (percentage); PCS – percentage cover score; HE – semi-arid heath model (Cruz et al. 2010); MH1 – mallee heath (McCaw 1997); MH2, MH3 – semi-arid mallee heath (Cruz et al. 2010); SH – shrubland (Catchpole et al. 1998); HG - (Burrows et al. 2009).

Conclusions

Validation of fire prediction simulators requires detailed data on the following:

- Fireground weather
- Fireground fuel types and fuel loads
- Location of ignition
- Mapping of fire perimeters at regular time intervals
- Fire behaviour models needed for more fuel types, fuel structures and for extreme fire conditions

Validation is time consuming and costly, but is necessary if simulation technology is to be increasingly used.