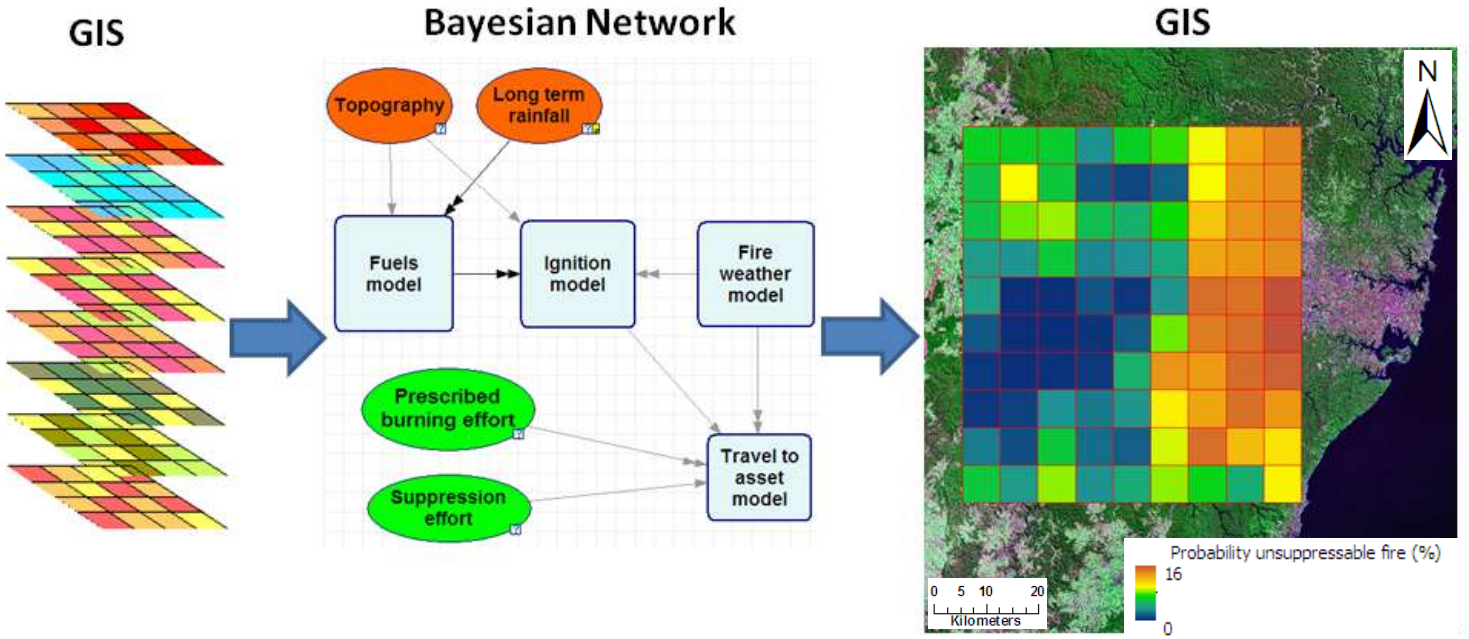
Spatially explicit fire danger assessment linking Bayesian networks to Geographic Information System



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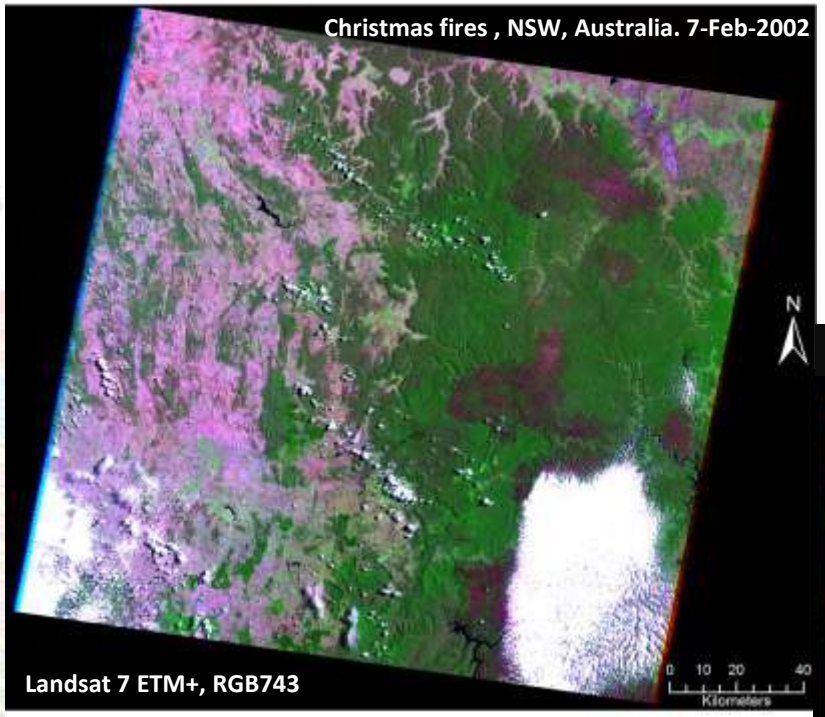
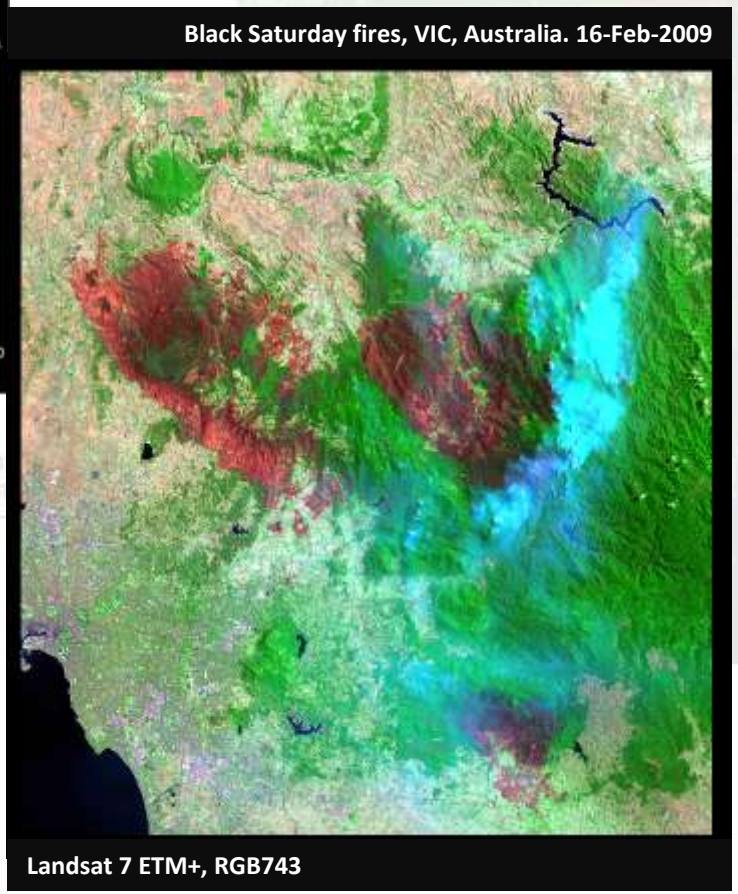
Introduction: Fire danger assessment





- *Complex natural phenomenon*

- *Impact on human communities (e.g., property)*

- *Fire danger rating systems: measure potential for fires/impact on property*

Introduction: Fire danger assessment

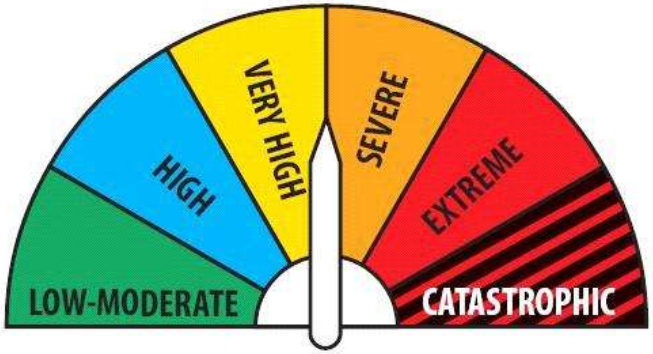
Numerical indices for easy interpretation

USA → National Fire Danger Rating System
Variables: weather, terrain and several fuel types

Canada (Argentina, Spain and Malaysia) → Fire Weather Index
Variables: weather and fuel layers

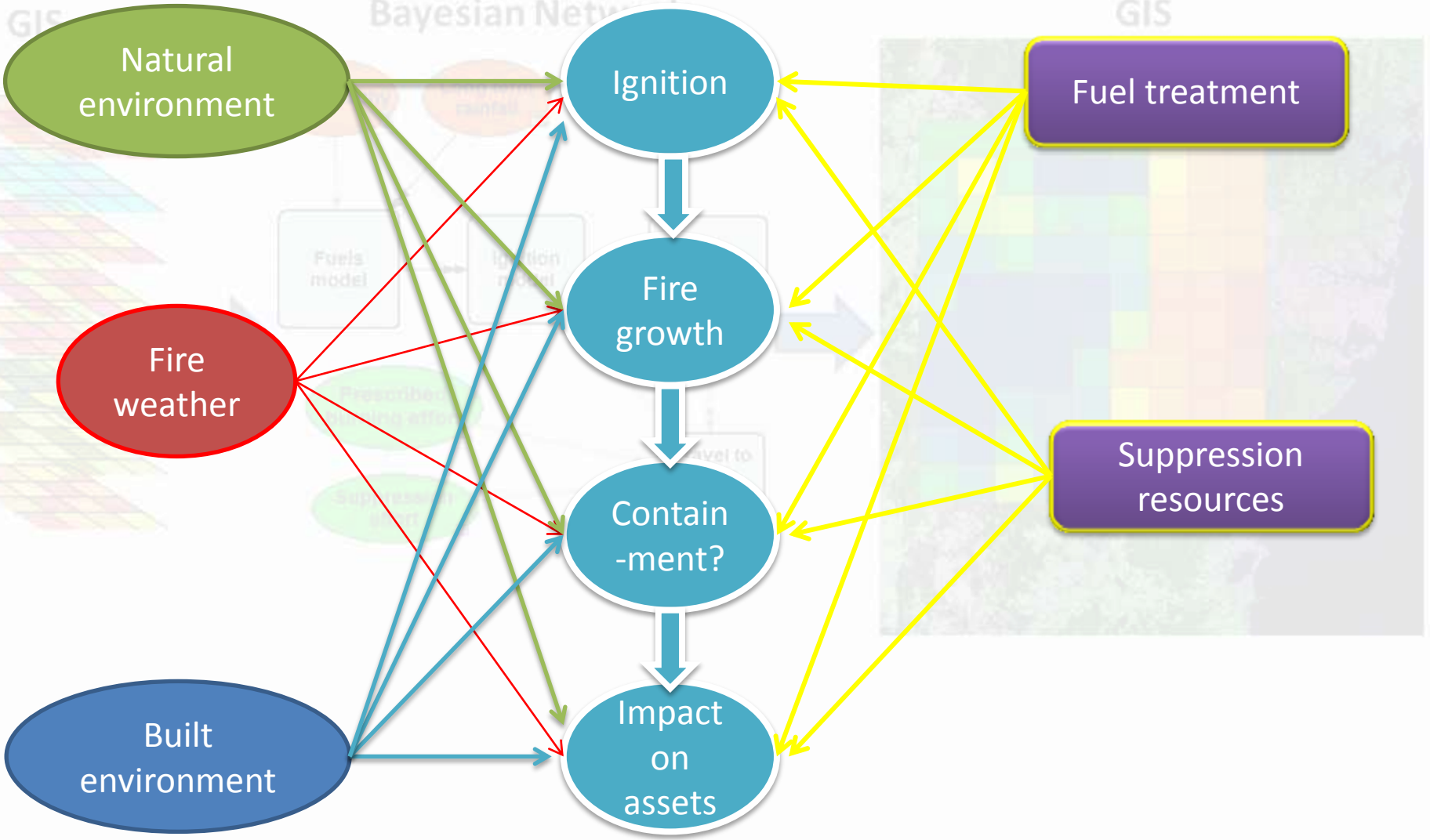
Australia → McArthur's Fire danger Rating System
Variables: weather and fuel type

South Africa → Lowveld Model
Variables: weather



Introduction: Fire danger assessment

Process of impact of fire on assets is complex



Aims

Develop a probabilistic framework for use as a fire danger rating system:

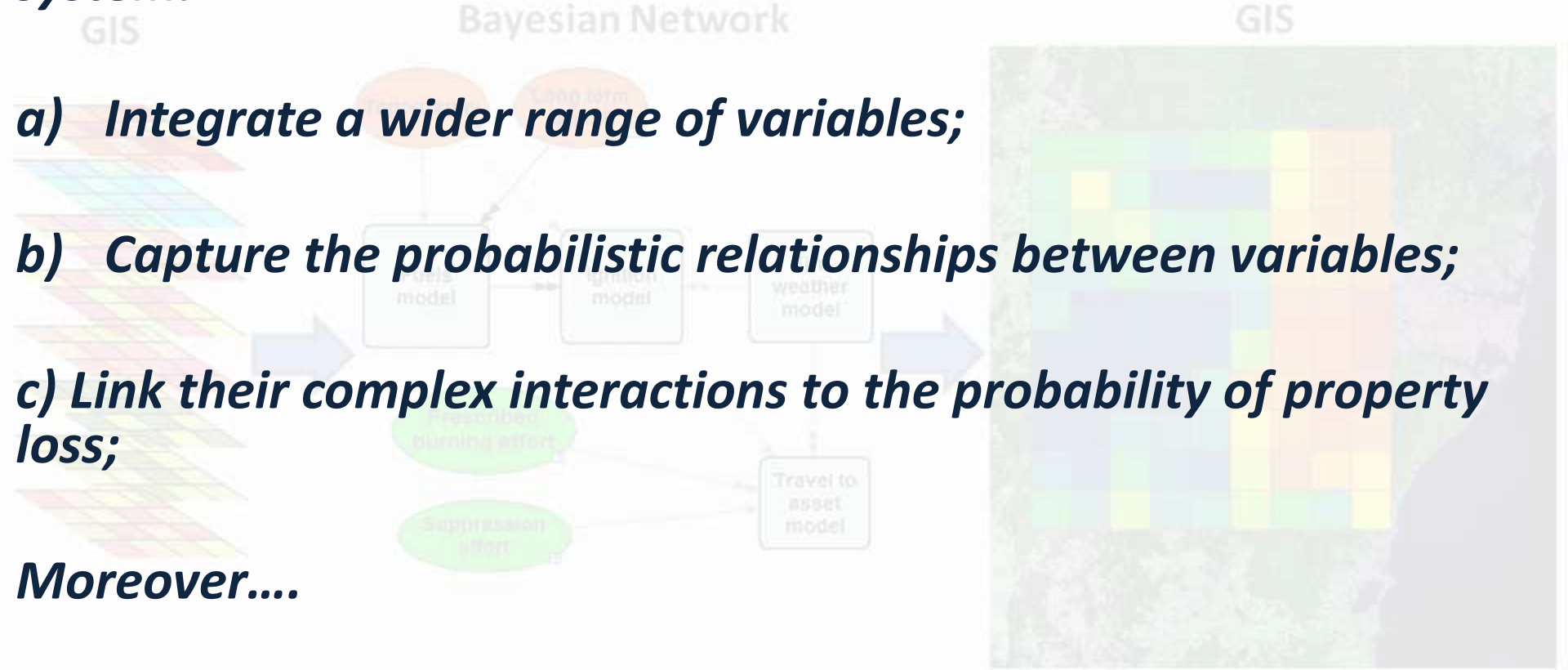
a) Integrate a wider range of variables;

b) Capture the probabilistic relationships between variables;

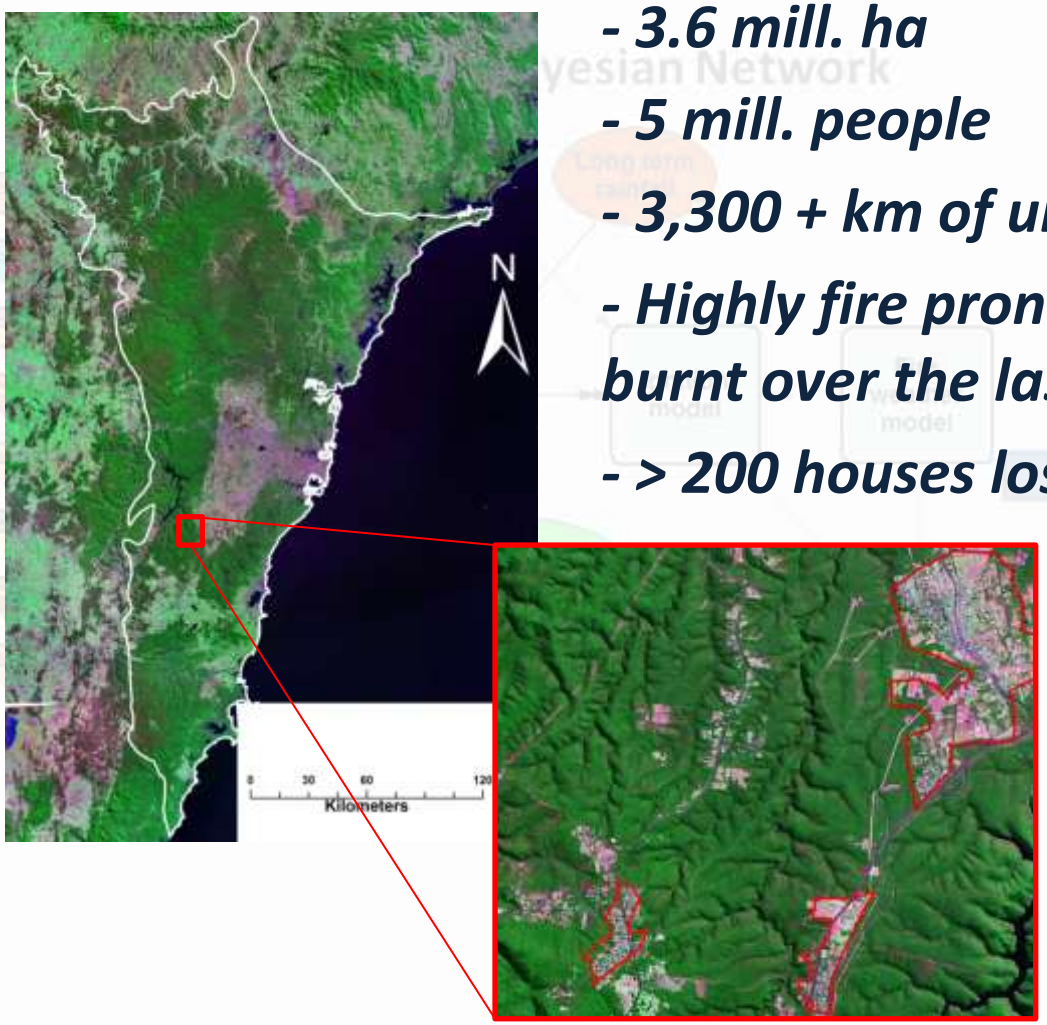
c) Link their complex interactions to the probability of property loss;

Moreover….

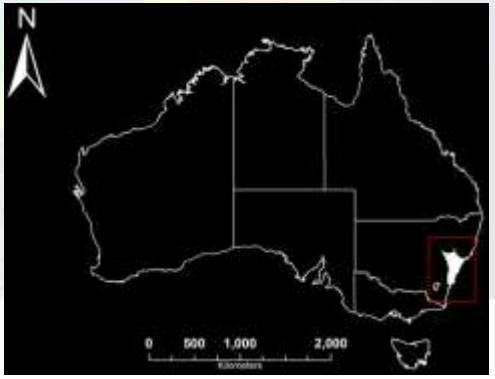
d) Spatially explicit (i.e., 10km) outputs at fine temporal resolution (i.e., daily)



Study area: Sydney Basin

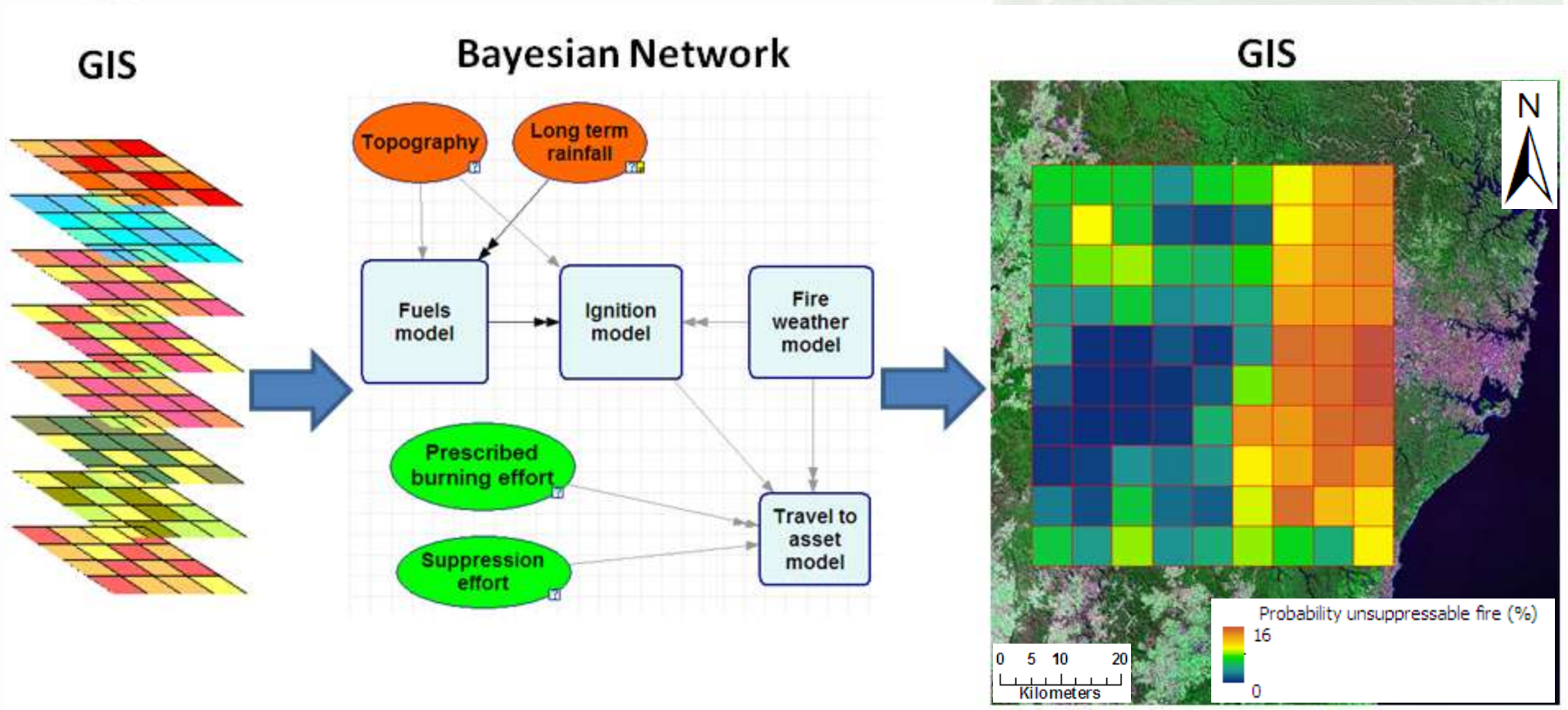


- 3.6 mill. ha
- 5 mill. people
- 3,300 + km of urban interface
- Highly fire prone landscape (over 1mill. ha burnt over the last 12 years)
- > 200 houses lost per decade

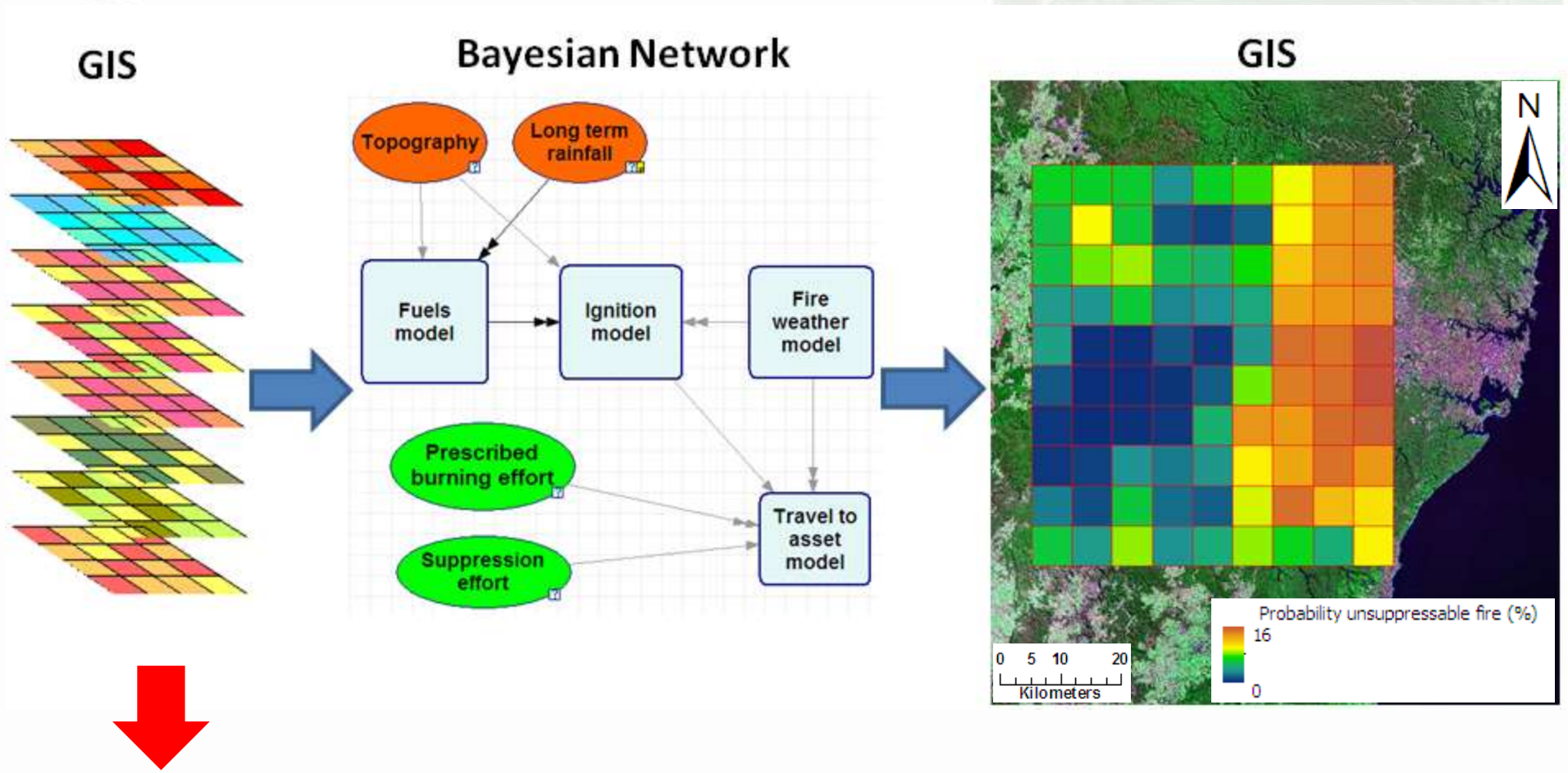


Approach

…GIS input to, and output from BN (after Johnson et al., 2011)

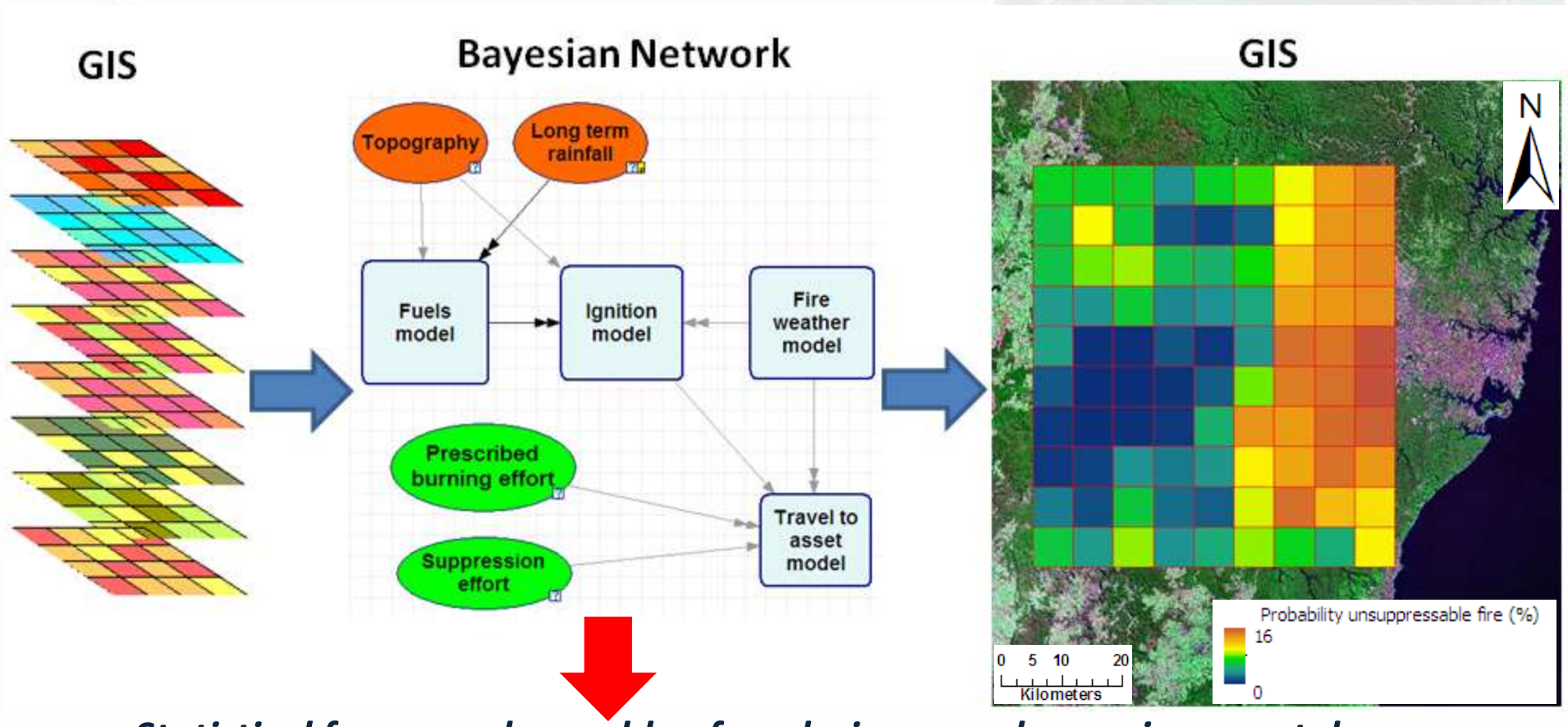


Approach



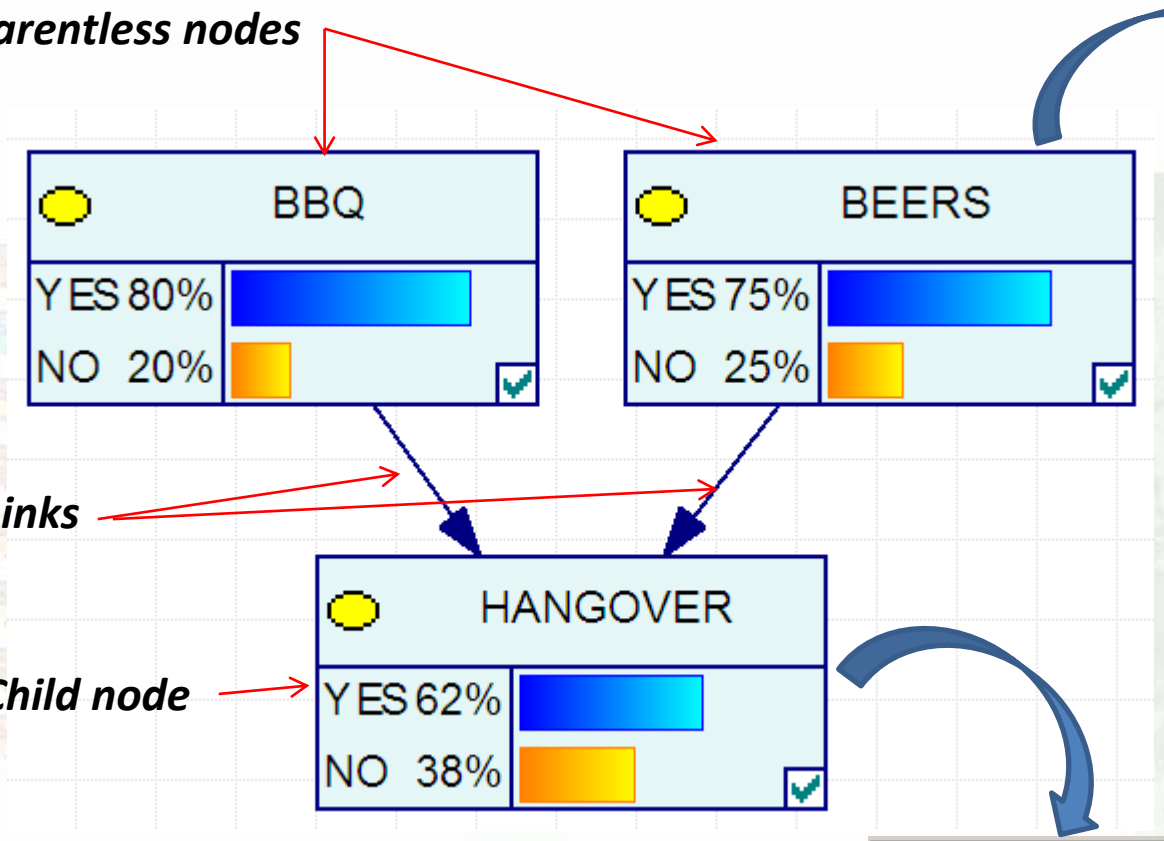
Incorporate the complexities of spatial dimension

Approach



Statistical framework capable of analysing complex environmental relationships and capture the probabilistic relationship between variables

Background: Bayesian belief network



YES	0.75
NO	0.25

Conditional Probability Tables

BBQ	YES		NO	
BEERS	YES	NO	YES	NO
YES	0.9	0	0.5	0
NO	0.1	1	0.5	1

Based on Bayes Theorem

$$P(A|B) = \frac{P(B|A)\,P(A)}{P(B)}$$

Data and methods: BN model

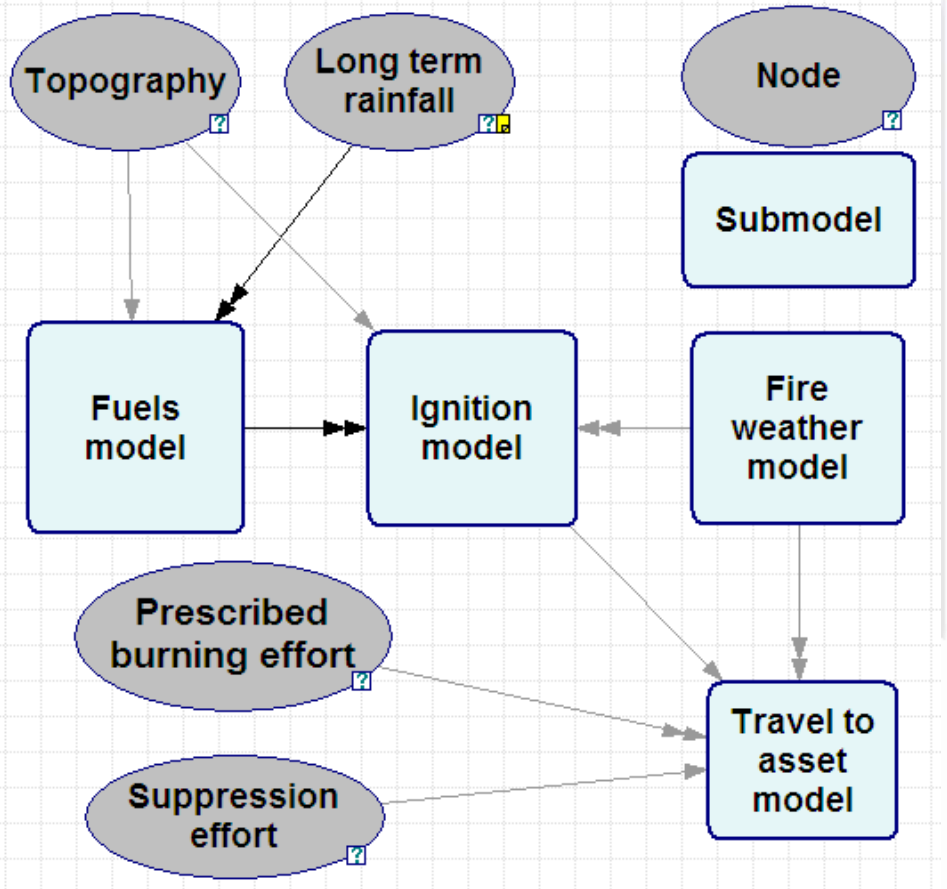
Node	Description	State
Topography	Terrain characteristics	Ridge, Slope, Gully
Distance to Road	Distance (m) to nearest mapped road (including fire trails)	<500, 500-1000, 1000-3000, >3000
House density	House density within 2km radius	0, 0-5, 5-20, >20
Elevation	Elevation (m) relative to sea level	0-300 m; 300-800m; greater than 800m
Powerline	Absence/presence of powerline	YES, NO
Region	Landscape characteristics	Blue Mountains, Hornsby, Woronora
Distance to WUI	Distance to wildland/urban interface (WUI). Distances were calculated along eight directions (i.e., N, 337.5-22.5; NE, 22.5-67.5; E, 67.5-112.5; SE, 112.5-157.5; S, 157.5-202.5; SW, 202.5-247.5; W, 247.5-292.5; NW, 292.5-337.5) and classified into six classes (i.e., <1km, 1-2.5km, 2.5-5km, 5-10km, 10-20km, >20km).	48 states resulting from the combination of eight direction and 6 distance classes
Gully Fuel Type	Type of fuel in Gully areas	Wet Sclerophyll Forest, Dry Sclerophyll Forest, Heath, Grassy woodland, Cleared
Slope Fuel Type	Type of fuel in Slope areas	Wet Sclerophyll Forest, Dry Sclerophyll Forest, Heath, Grassy woodland, Cleared
Ridge Fuel Type	Type of fuel in Ridge areas	Wet Sclerophyll Forest, Dry Sclerophyll Forest, Heath, Grassy woodland, Cleared
Prescribed burning effort	Chosen level of prescribed burning effort for the season	0, 1, 5, 10
Initial attack effort	Chosen level of initial attack effort available for the season	None, Ground, Air and ground, RAFT
Long term rainfall	12-month precipitation anomaly	< -10% long term average, >-10% and <10% long term average, >10% long term average
Ridge Fire Frequency	Fire frequency (events in the last 30 years) in Ridge areas	0, 1-2, 3-4, >4
Ridge Time Since Fire	Time Since Fire (years) in Ridge areas	1-3, 3-6, 6-9, 9-15, >15
Slope Fire Frequency	Fire frequency (events in the last 30 years) in Slope areas	0, 1-2, 3-4, >4
Slope Time Since Fire	Time Since Fire (years) in Slope areas	1-3, 3-6, 6-9, 9-15, >15
Gully Fire Frequency	Fire frequency (events in the last 30 years) in Gully areas	0, 1-2, 3-4, >4
Gully Time Since Fire	Time Since Fire (years) in Gully areas	1-3, 3-6, 6-9, 9-15, >15
Wind direction	Wind direction (degree)	North, North-East, East, South-East, South, South-West, West, North-West
Temperature	Max temperature (°C)	<20, 20-25, 25-30, 30-35, >35
Precipitation	Precipitation (mm)	0, 0-5, 5-10, 10-20, >20

58 nodes

22 parentless nodes (GIS-sourced)

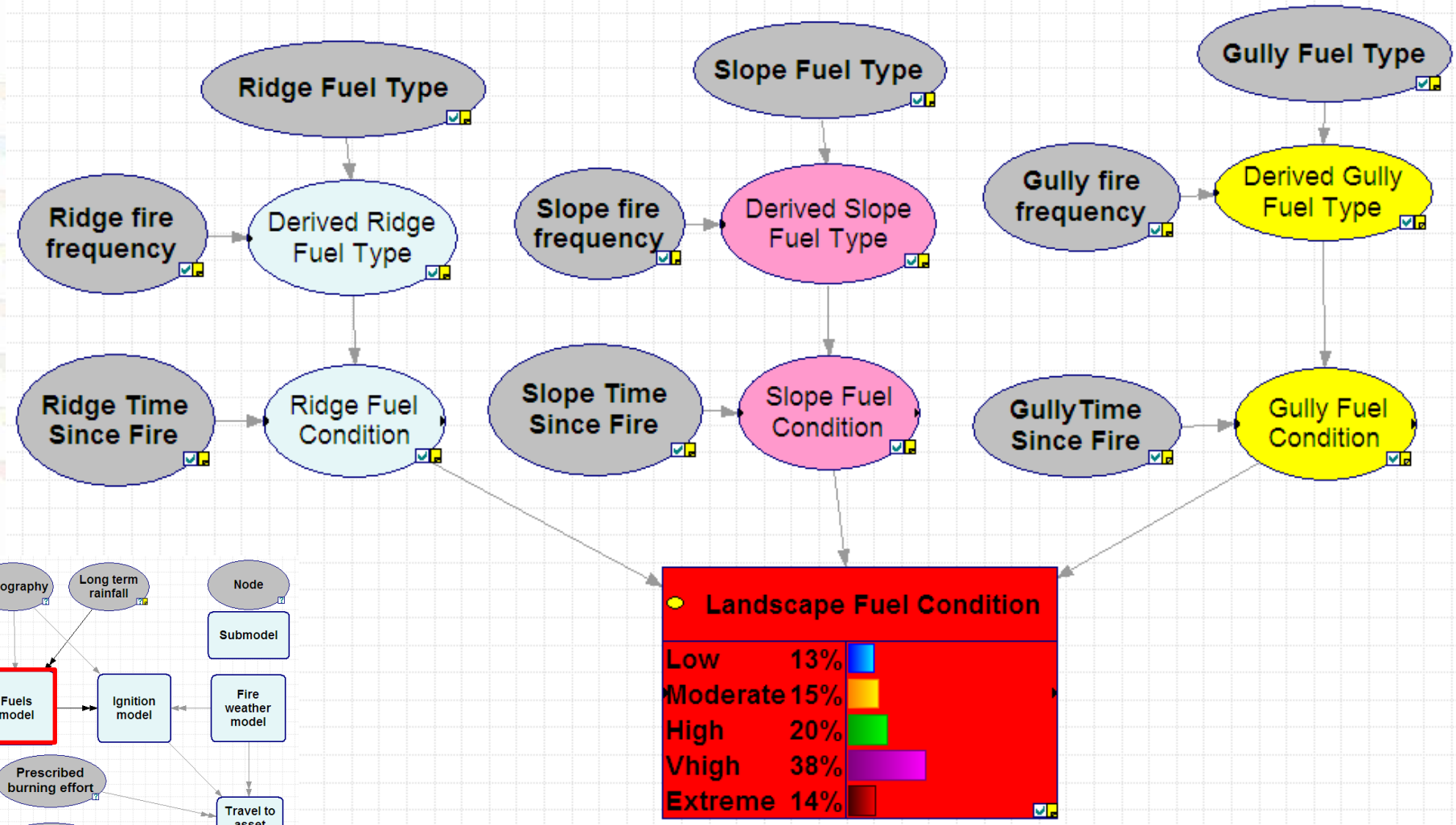
112 links

5 submodels



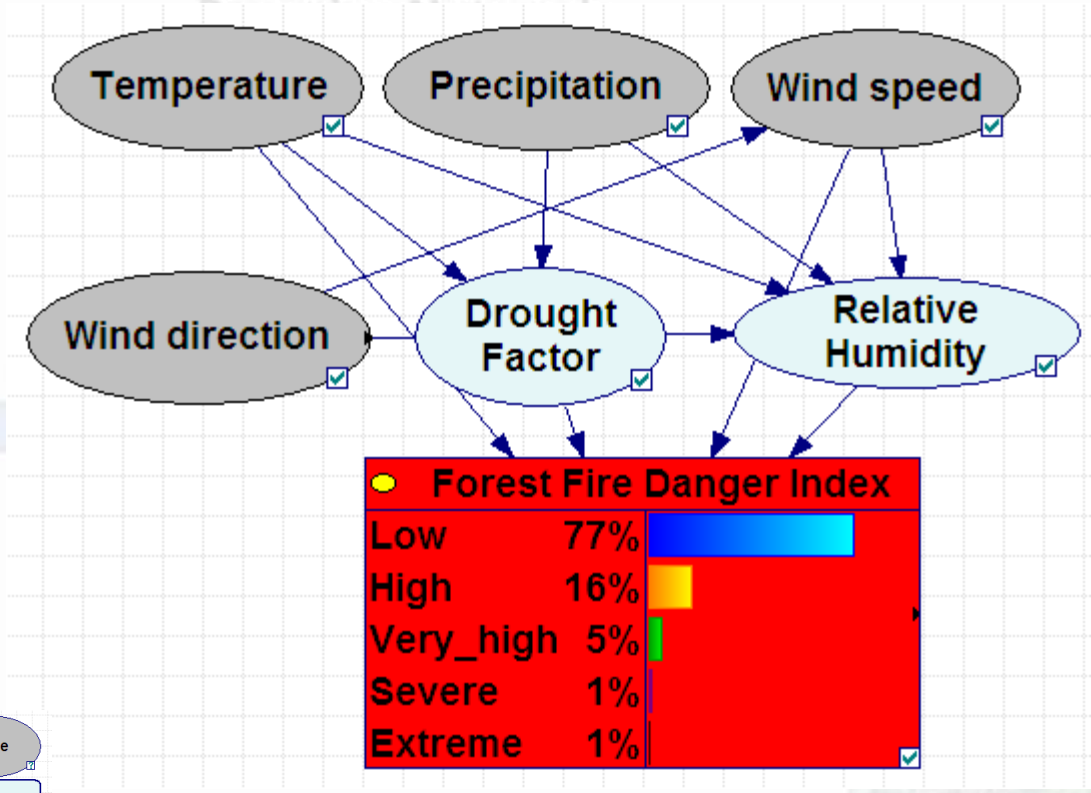
Data and methods: BN model

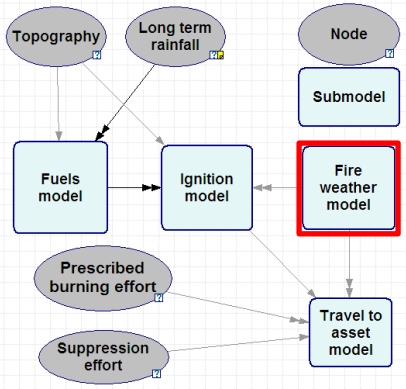
Fuels model



Data and methods: BN model

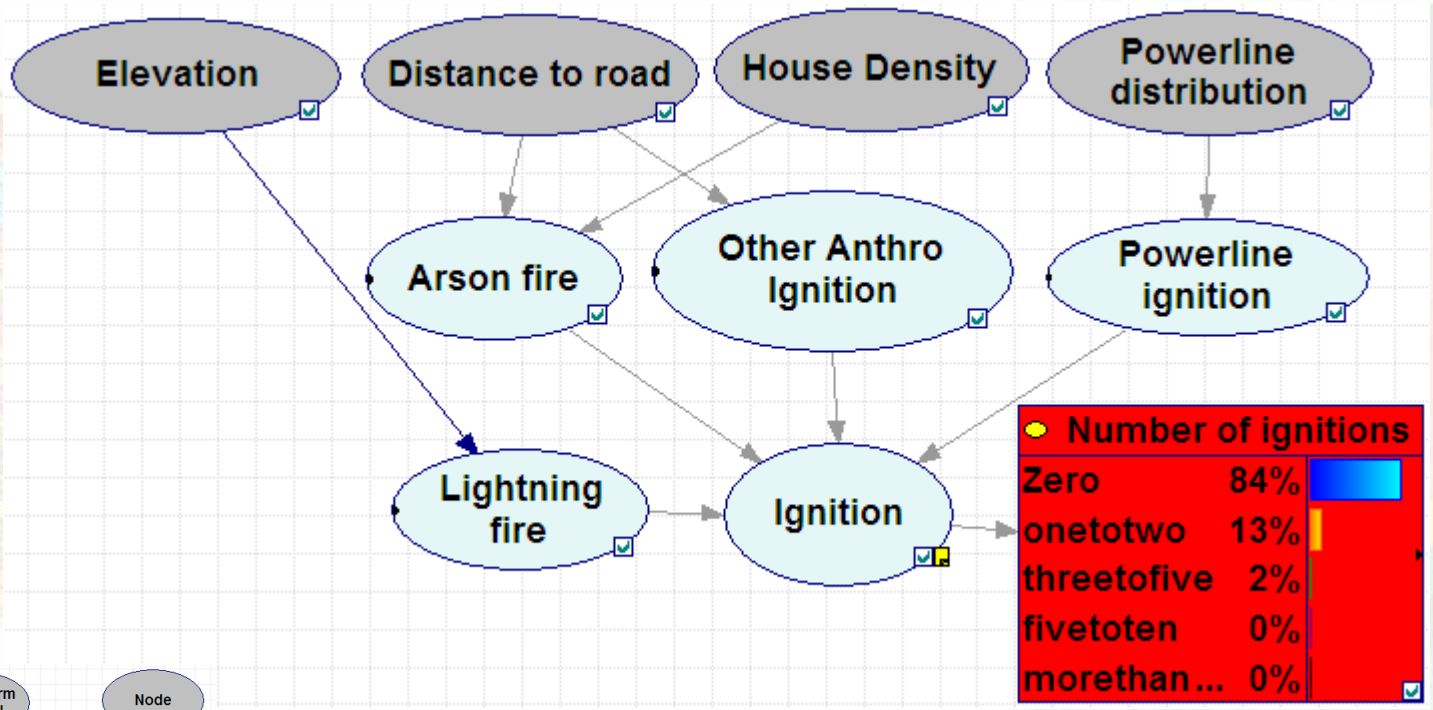
Fire weather model

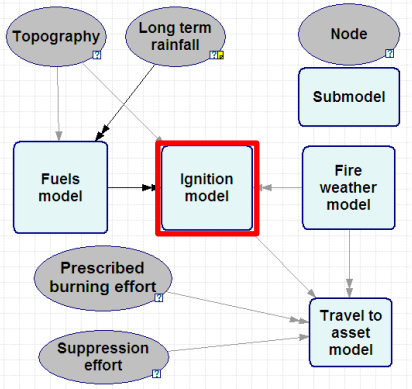




Data and methods: BN model

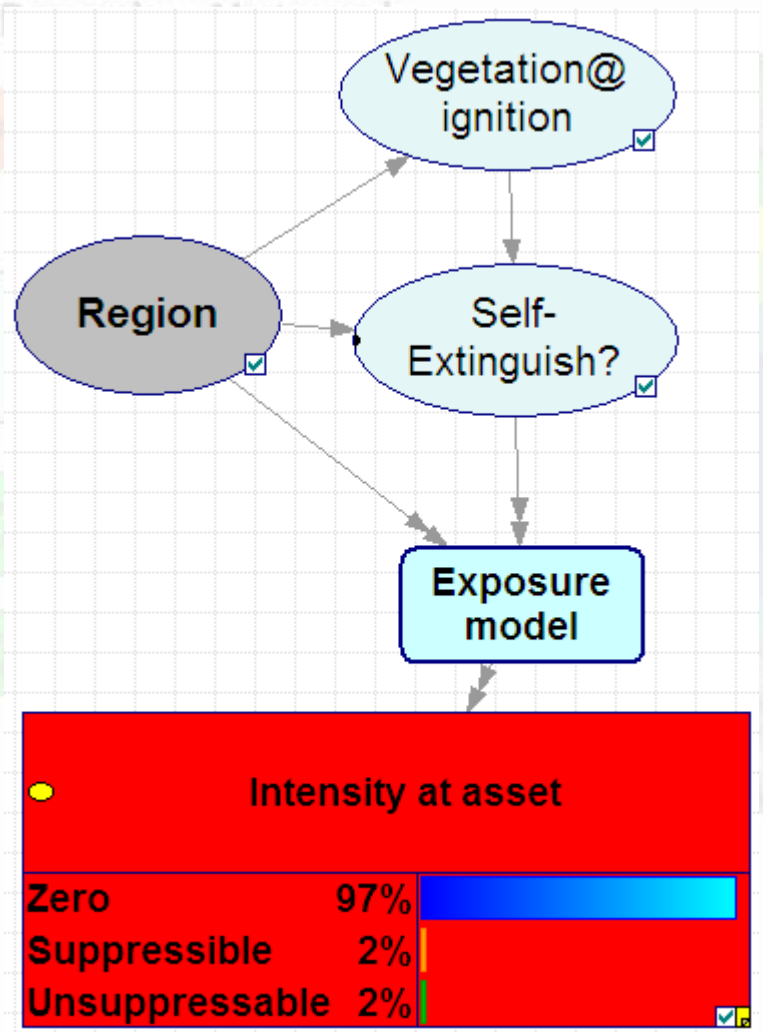
Ignition model

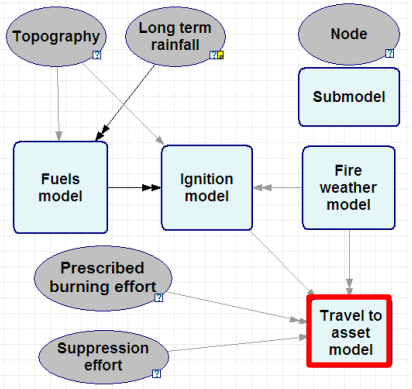




Data and methods: BN model

Travel to asset model

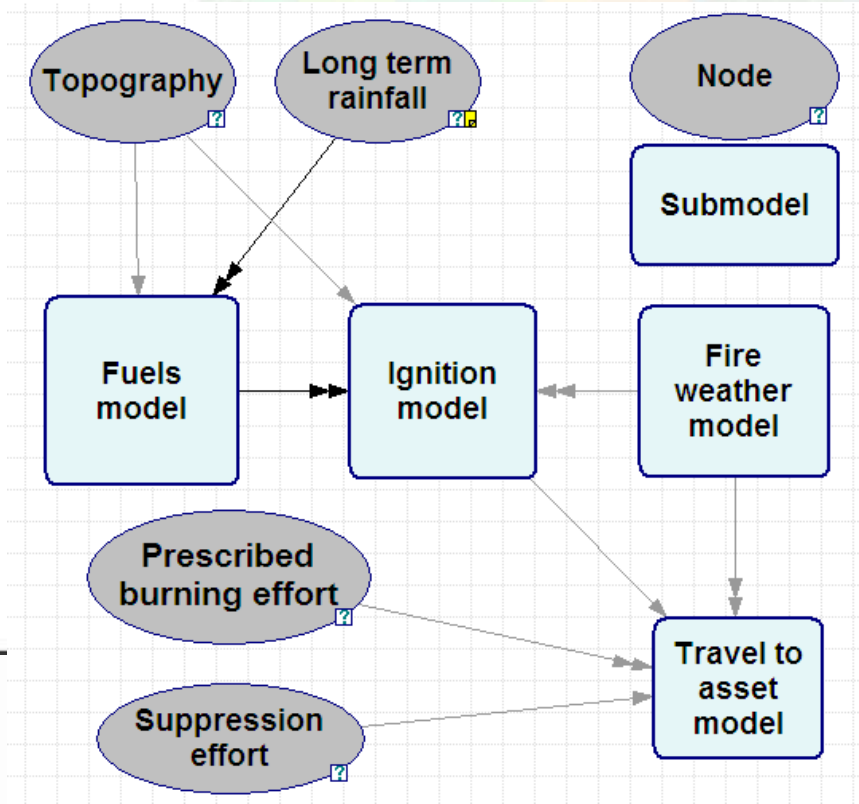




Data and methods: GIS data

Node	Data source
Topography	NSW DLPI
Distance to Road	NSW DLPI
House density	NSW DLPI
Powerline	NSW DLPI
Region	N/A
Distance to WUI	Derived from Keith (2004) and NSW DLPI
Gully Fuel Type	Keith (2004)
Slope Fuel Type	Keith (2004)
Ridge Fuel Type	Keith (2004)
Prescribed burning effort	N/A
Initial attack effort	N/A
Long term rainfall	Bureau of meteorology
Ridge Fire Frequency	NSW NPWS fire history data
Ridge Time Since Fire	NSW NPWS fire history data
Slope Fire Frequency	NSW NPWS fire history data
Slope Time Since Fire	NSW NPWS fire history data
Gully Fire Frequency	NSW NPWS fire history data
Gully Time Since Fire	NSW NPWS fire history data
Wind direction	Bureau of meteorology
Temperature	Bureau of meteorology
Precipitation	Bureau of meteorology
Wind Speed	Bureau of meteorology
Ignition	NSW NPWS fire history data

GIS layers required to provide all input variables (i.e., parentless nodes) of BN with spatially explicit information



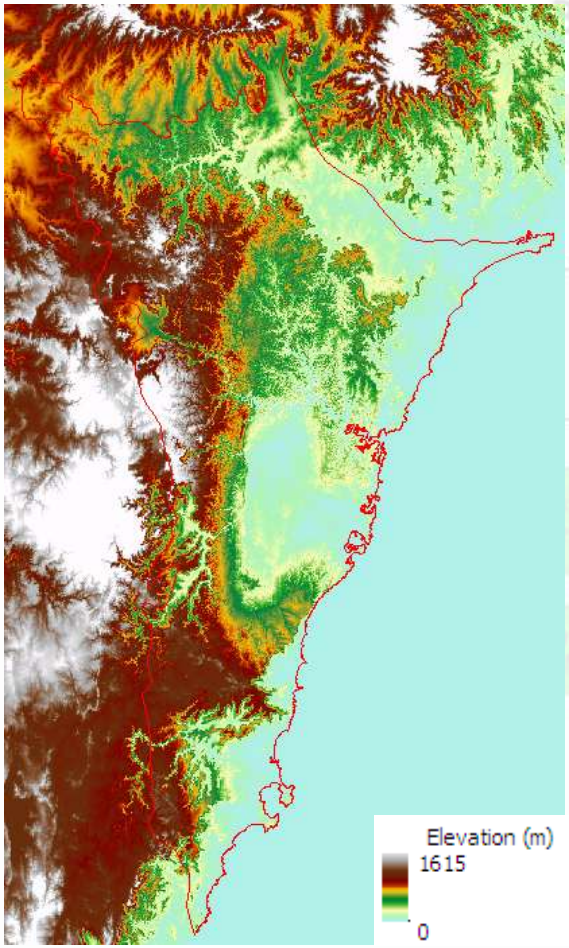
Data and methods: GIS data

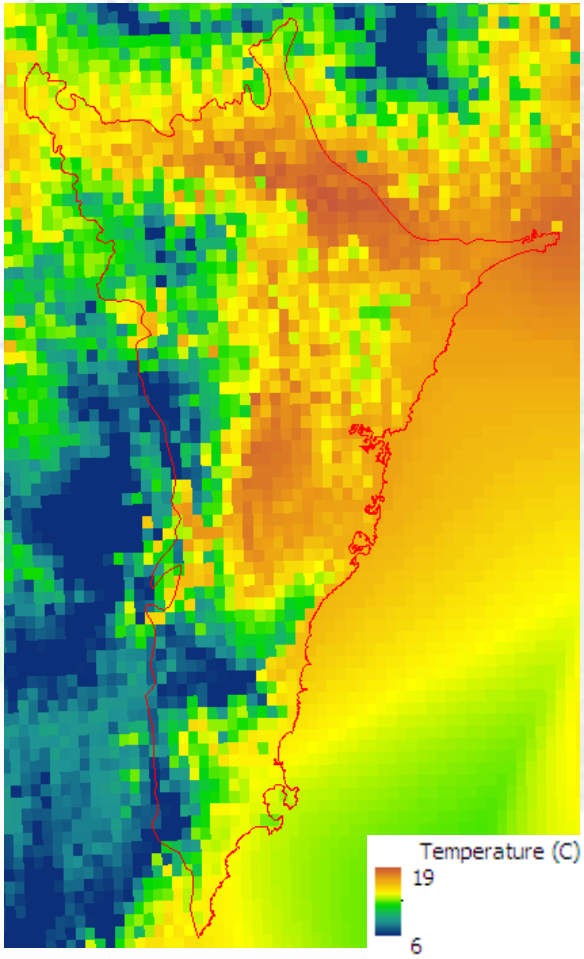
Static

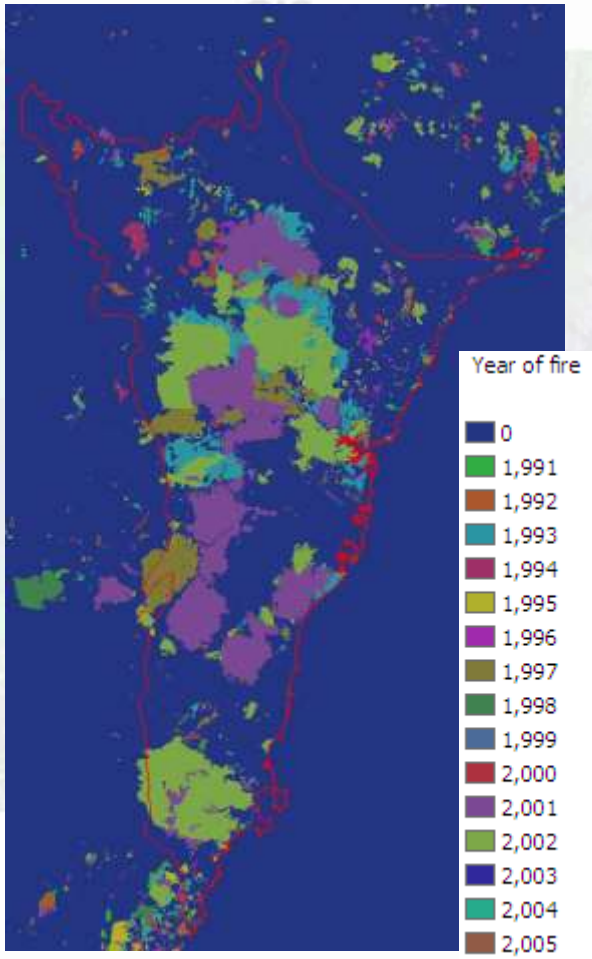
Dynamic

Highly (i.e.,Daily)

Moderately (e.g., Seasonal)







Topography, fuel types, powerline distribution

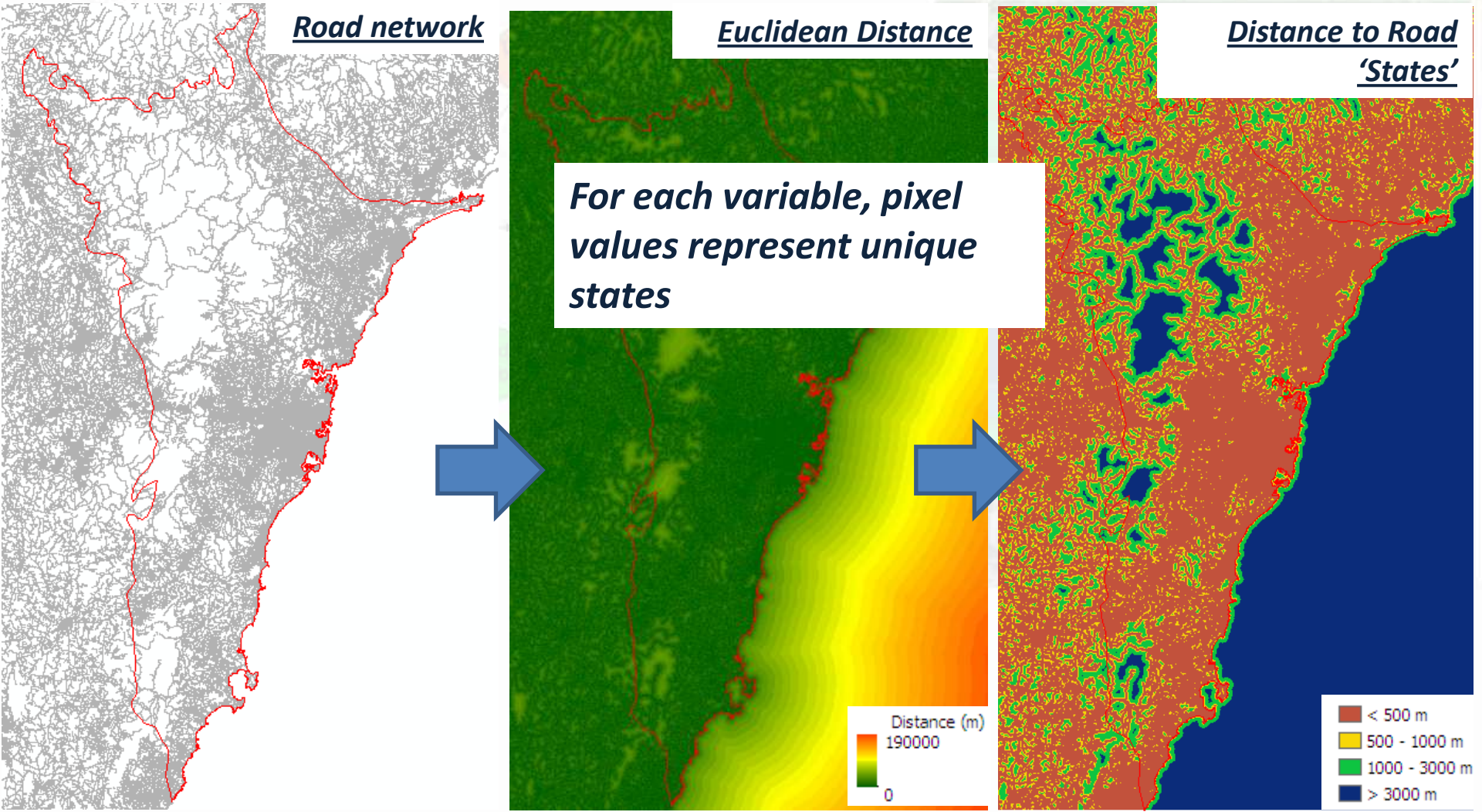
Precipitation, temperature, wind

Time since fire, fire frequency, long term rainfall

Data and methods: GIS data

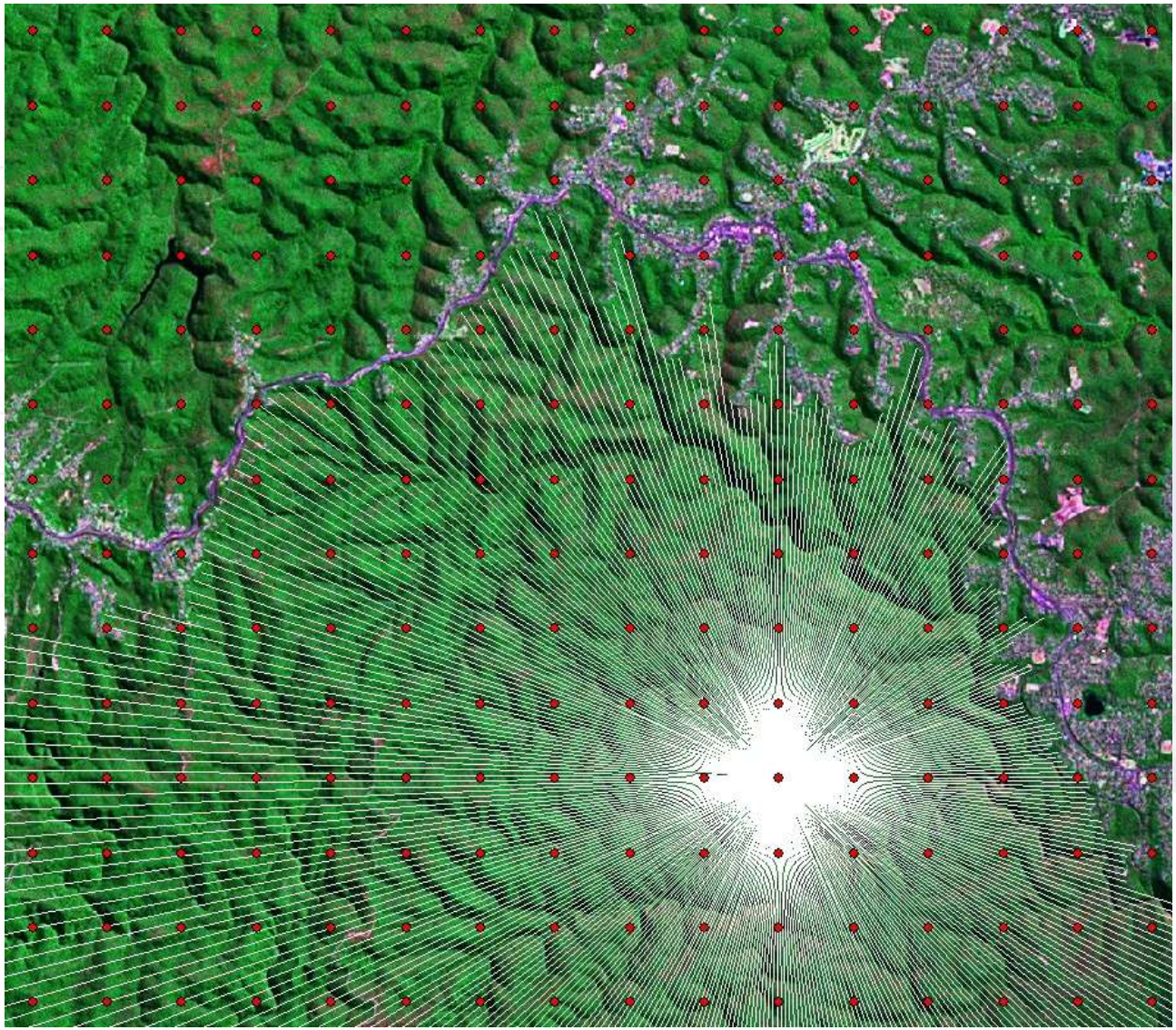
From raw GIS data to spatially explicit measurements of the states of all input variables (i.e., parentless nodes)

Distance to Road	**Distance (m) to nearest mapped road (including fire trails)**	**<500, 500-1000, 1000-3000, >3000**



Data and methods: GIS data

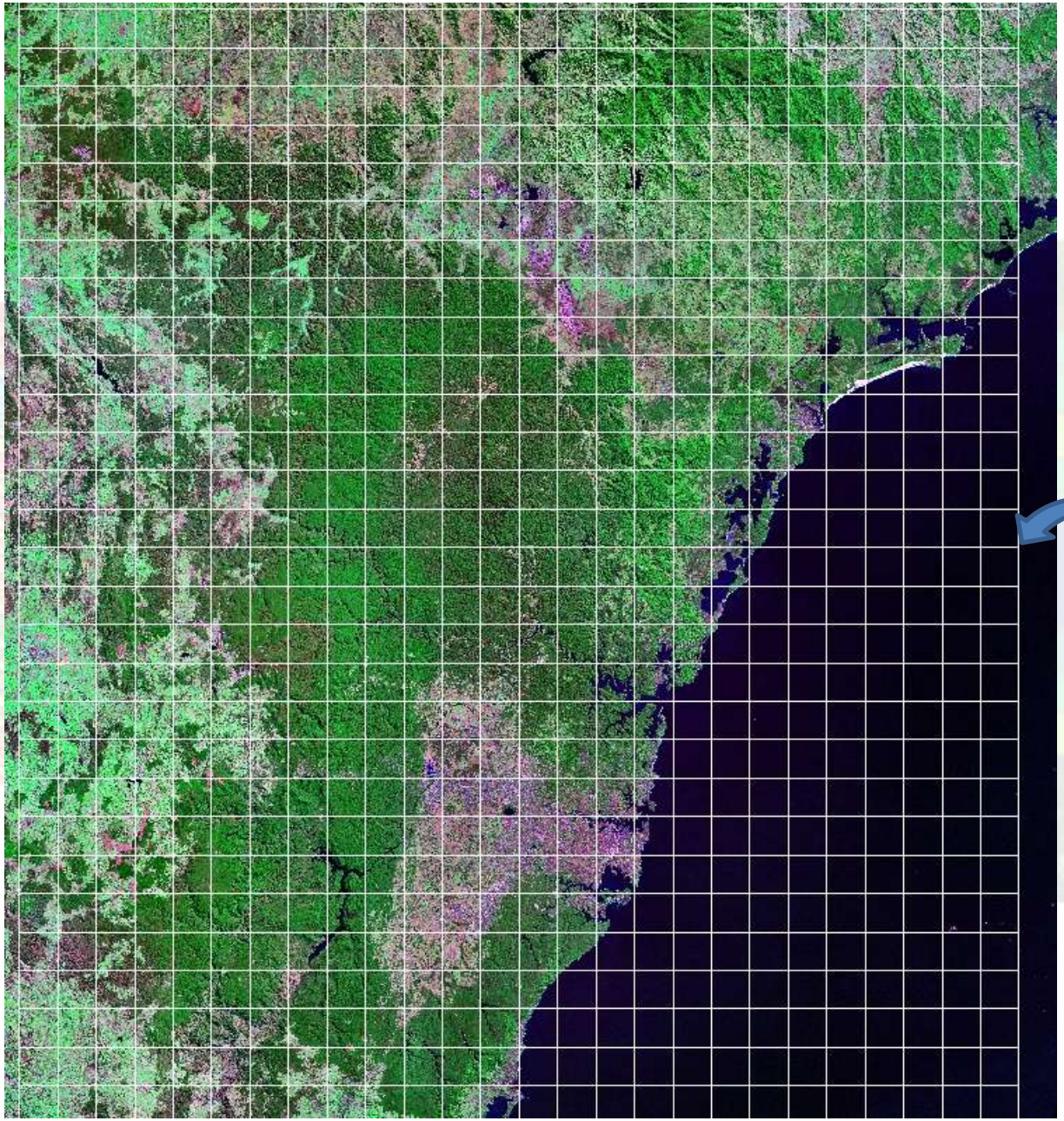
From raw GIS data to spatially explicit measurements of the states of all input variables (i.e., parentless nodes)



Distance to closest 'wildland/urban' interface across 360° at 1km resolution

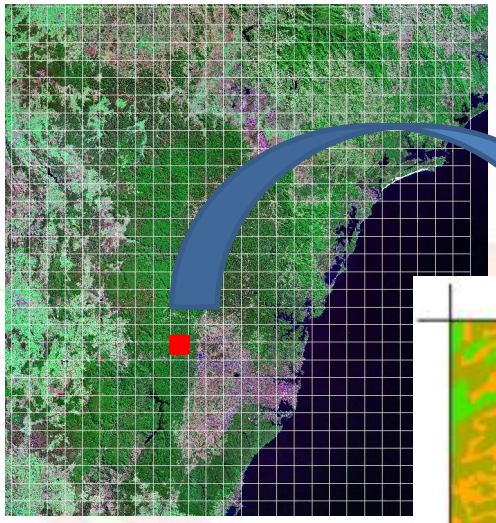
Distribution of 6 distance classes (i.e., <1km, 1-2.5Km, 2.5-5Km, 5-10Km, 10-20Km, >20Km) across 8 direction classes (i.e., N, NE, E, SE, S, SW, W, NW) at 1km resolution

Data and methods: GIS and BN integration

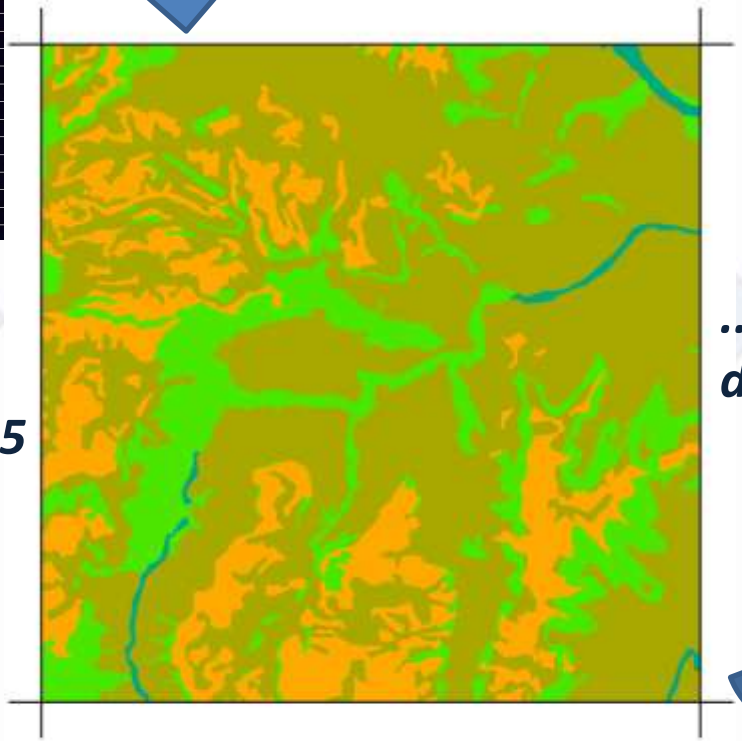


10Km units.....but not necessarily!!

Data and methods: GIS and BN integration



Automatic procedure (Python) to calculate and extract the % cover of each 'state' from all GIS variables (i.e., parentless nodes) within each unit....



Unit #345

....and save it as 'states distribution' for that unit

ID	WSF	DSF	H	GW
345	0.16	0.62	0.2	0.02

VEGETATION TYPE
% Cover
WET SCLEROPHYLL FOREST: 16%
DRY SCLEROPHYLL FOREST: 62%
HEATH: 20%
GRASSY WOODLAND: 2%

Data and methods: GIS and BN integration

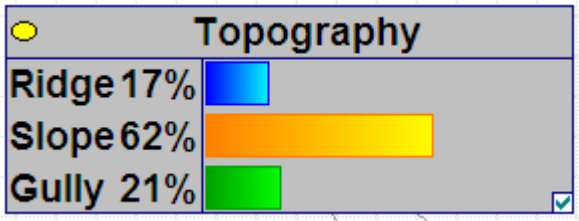
One input file for each time-step of analysis (i.e., day)…..

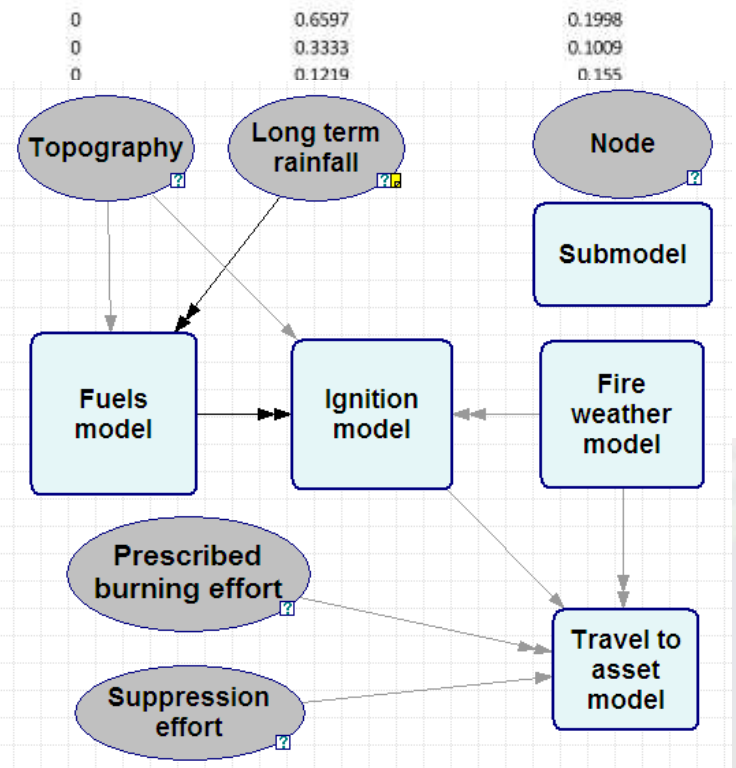
ID	Topography_1	Topography_2	Topography_3	LM2_percentage_1	LM2_percentage_2	LM2_percentage_3	LM2_percentage_4	Initial_attack_1	Initial_attack_2	Initial_attack_3	Initial_attack_4	LM2_D3RD_1	LM2_D3RD_2	LM2_D3RD_3	LM2_D3RD_4	LM2_house_dens_2km_1	LM2_house_dens_2km_2	LM2_house_dens_2km_3
1	0.1713187	0.2344337	0.2052375	0	1	0	0	1	0	0	0	0.868125	0.13375	0.008131	0	0.179	0.4036	0.2174
2	0.1520875	0.5803375	0.2879375	0	1	0	0	1	0	0	0	0.82125	0.075625	0.003125	0	0.1189	0.3258	0.1918
3	0.2366375	0.5103625	0.2530063	0	1	0	0	1	0	0	0	0.87	0.08875	0.04125	0	0.2002	0.5189	0.1954
4	0.20255	0.635787	0.1616625	0	1	0	0	1	0	0	0	0.340625	0.186875	0.4175	0.055	0.7772	0.2226	0
5	0.2845062	0.59114375	0.12435	0	1	0	0	1	0	0	0	0.614375	0.208125	0.175623	0.001875	0.4224	0.4806	0.076
6	0.3672375	0.5345625	0.0982	0	1	0	0	1	0	0	0	0.66625	0.219625	0.138125	0	0.6597	0.2998	0.1405
7	0.3491126	0.61154375	0.13934375	0	1	0	0	1	0	0	0	0.80875	0.109625	0.085625	0	0.3333	0.5009	0.2036
8	0.26343125	0.5455188	0.19063	0	1	0	0	1	0	0	0	0.96125	0.0375	0.00125	0	0.1219	0.155	0.4353
9	0.1720125	0.422925	0.4050625	0	1	0	0	1	0	0	0	0.968125	0.031875	0	0	0.0691	0.2639	0.5754
10	0.21528125	0.62093125	0.1677875	0	1	0	0	1	0	0	0	0.861875	0.120625	0.0175	0	0.0922	0.8993	0.0087
11	0.127075	0.61116	0.261775	0	1	0	0	1	0	0	0	0.946875	0.053125	0	0	0.089	0.8668	0.0441
12	0.21315625	0.5495375	0.23730625	0	1	0	0	1	0	0	0	0.9375	0.0625	0	0	0.1107	0.3554	0.341
13	0.289025	0.50686875	0.20410625	0	1	0	0	1	0	0	0	0.70875	0.21	0.08125	0	0.8051	0.0286	0.0427
14	0.266975	0.57151875	0.15950625	0	1	0	0	1	0	0	0	0.23375	0.173125	0.454375	0.13875	0.9476	0.0524	0
15	0.2902125	0.551331	0.14945	0	1	0	0	1	0	0	0	0.241875	0.1625	0.428125	0.1675	0.9971	0.0027	0.0002
16	0.15488975	0.6483875	0.19691875	0	1	0	0	1	0	0	0	0.883125	0.0775	0.039375	0	0.1797	0.0485	0.5275
17	0.19591875	0.4466	0.3574813	0	1	0	0	1	0	0	0	0.989	0.006	0	0	0	0	0.1665
18	0.13581875	0.49223125	0.37195	0	1	0	0	1	0	0	0	0.99125	0.00875	0	0	0	0	0.224
19	0.1817	0.5054875	0.2228125	0	1	0	0	1	0	0	0	0.965	0.035	0	0	0.2095	0.7053	0.0852
20	0.1383625	0.5790375	0.2827187	0	1	0	0	1	0	0	0	0.8525	0.144375	0.025125	0	0.2725	0.7219	0.0056
21	0.1918675	0.5426937	0.2653187	0	1	0	0	1	0	0	0	0.843125	0.149375	0.0075	0	0.3435	0.5472	0.043
22	0.355125	0.5340875	0.1098875	0	1	0	0	1	0	0	0	0.94625	0.053125	0.000625	0	0.188	0.8511	0.055
23	0.2719375	0.6111875	0.11694375	0	1	0	0	1	0	0	0	0.6675	0.229375	0.123125	0	0.5477	0.0352	0.0665
24	0.3279187	0.553675	0.11840625	0	1	0	0	1	0	0	0	0.8325	0.13625	0.03125	0	0.4018	0.0411	0.1325
25	0.2636	0.50913125	0.22726875	0	1	0	0	1	0	0	0	0.96625	0.031875	0.001875	0	0.0125	0.0181	0.3779
26	0.1939125	0.62014375	0.18594375	0	1	0	0	1	0	0	0	0.97625	0.02375	0	0	0	0.0193	0.2192
27	0.1953187	0.5984875	0.20619375	0	1	0	0	1	0	0	0	0.9625	0.0375	0	0	0	0	0.0308
28	0.2014187	0.6065125	0.19206	0	1	0	0	1	0	0	0	0.908125	0.085625	0.00625	0	0.771	0.229	0
29	0.2563687	0.5978625	0.14656875	0	1	0	0	1	0	0	0	0.64875	0.221875	0.129375	0	0.9757	0.0243	0
30	0.2394375	0.5455063	0.2449	0	1	0	0	1	0	0	0	0.779875	0.183125	0.04	0	0.8083	0.1898	0.0019
31	0.17725	0.6668125	0.2560437	0	1	0	0	1	0	0	0	0.569	0.225	0.21	0	0.7589	0.2502	0.0759
32	0.2508562	0.647575	0.10156875	0	1	0	0	1	0	0	0	0.6925	0.134375	0.113125	0	0.7049	0.0379	0.0691
33	0.2967	0.5803375	0.1229625	0	1	0	0	1	0	0	0	0.54875	0.241875	0.209375	0	0.8889	0.0254	0.0286
34	0.2121875	0.54545	0.24236875	0	1	0	0	1	0	0	0	0.993125	0.006875	0	0	0.0988	0.0753	0.0452
35	0.1407187	0.6064875	0.25279375	0	1	0	0	1	0	0	0	0.9975	0.0025	0	0	0.0013	0.0467	0.0724
36	0.12067505	0.58902778	0.3102796717	0	1	0	0	1	0	0	0	0.951875	0.045	0.003125	0	0	0.0046	0.1216
37	0.246625	0.5983375	0.1549375	0	1	0	0	1	0	0	0	0.775625	0.13625	0.078125	0	0.7819	0.2184	0
38	0.1985625	0.6232375	0.17816875	0	1	0	0	1	0	0	0	0.215625	0.11	0.39125	0.283125	1	0	0
39	0.2057187	0.5916	0.20268125	0	1	0	0	1	0	0	0	0.25	0.17875	0.49125	0.08	1	0	0
40	0.1720937	0.5294062	0.2985	0	1	0	0	1	0	0	0	0.4775	0.233125	0.229375	0	1	0	0
41	0.2166437	0.6439375	0.1489625	0	1	0	0	1	0	0	0	0.6025	0.234375	0.163125	0	1	0	0
42	0.1334	0.5149437	0.15165625	0	1	0	0	1	0	0	0	0.369375	0.193125	0.43375	0.00375	0.6982	0.0581	0.0146
43	0.21855	0.5946625	0.1787875	0	1	0	0	1	0	0	0	0.973125	0.026875	0	0	0.0035	0.1617	0.2711
44	0.15785	0.5183375	0.3238125	0	1	0	0	1	0	0	0	0.94375	0.05625	0	0	0.0031	0.3418	0.5892
45	0.1384875	0.614125	0.2773875	0	1	0	0	1	0	0	0	0.99125	0.00875	0	0	0	0	0.0089
46	0.2303125	0.5734125	0.196275	0	1	0	0	1	0	0	0	0.660625	0.251875	0.0875	0	0.8782	0.1218	0
47	0.2849375	0.5764	0.1586625	0	1	0	0	1	0	0	0	0.4125	0.184375	0.30125	0.121875	1	0	0
48	0.21133125	0.60993125	0.1793375	0	1	0	0	1	0	0	0	0.233125	0.58125	0.439375	0.14625	1	0	0
49	0.14814375	0.5853125	0.26634375	0	1	0	0	1	0	0	0	0.14375	0.0075	0.343125	0.415625	1	0	0
50	0.148075	0.4182625	0.4336625	0	1	0	0	1	0	0	0	0.155875	0.1025	0.445	0.295625	1	0	0
51	0.1897812	0.518125	0.14209375	0	1	0	0	1	0	0	0	0.729375	0.169375	0.11125	0	0.6692	0.1913	0.1386
52	0.1645	0.568725	0.266775	0	1	0	0	1	0	0	0	0.949375	0.04875	0.001875	0	0	0.484	0.4749
53	0.12520625	0.58665	0.27814375	0	1	0	0	1	0	0	0	0.97625	0.02375	0	0	0.0068	0.1813	0.1644
54	0.12223125	0.5582625	0.31950625	0	1	0	0	1	0	0	0	0.990625	0.009375	0	0	0	0.0005	0.0522
55	0.2497875	0.5794875	0.1707187	0	1	0	0	1	0	0	0	0.275625	0.196625	0.48375	0.045	1	0	0
56	0.21290375	0.58630625	0.1007	0	1	0	0	1	0	0	0	0.3	0.3275	0.405625	0.016875	1	0	0
57	0.19836875	0.59038125	0.21125	0	1	0	0	1	0	0	0	0.310625	0.135	0.415	0.001875	1	0	0
58	0.2330125	0.57298875	0.19461875	0	1	0	0	1	0	0	0	0	0	0.04625	0.95375	1	0	0
59	0.206137	0.45973375	0.33391875	0	1	0	0	1	0	0	0	0.388125	0.1075	0.27875	0.225625	0.8441	0.1523	0.0036
60	0.30404375	0.5705	0.12585625	0	1	0	0	1	0	0	0	0.063125	0.030875	0	0	0.1561	0.245	0.3283
61	0.1345062	0.576675	0.28881875	0	1	0	0	1	0	0	0	0.940625	0.059375	0	0	0.0005	0.1089	0.517
62	0.109825	0.9039875	0.2971675	0	1	0	0	1	0	0	0	0.988125	0.011875	0	0	0.0023	0.0158	0.0885
63	0.29811875	0.5223625	0.17851875	0	1	0	0	1	0	0	0	0.9475	0.040875	0.009625	0	0.2148	0.5018	0.0382

….to account for temporally dynamic data (e.g., weather)

Data and methods: GIS and BN integration

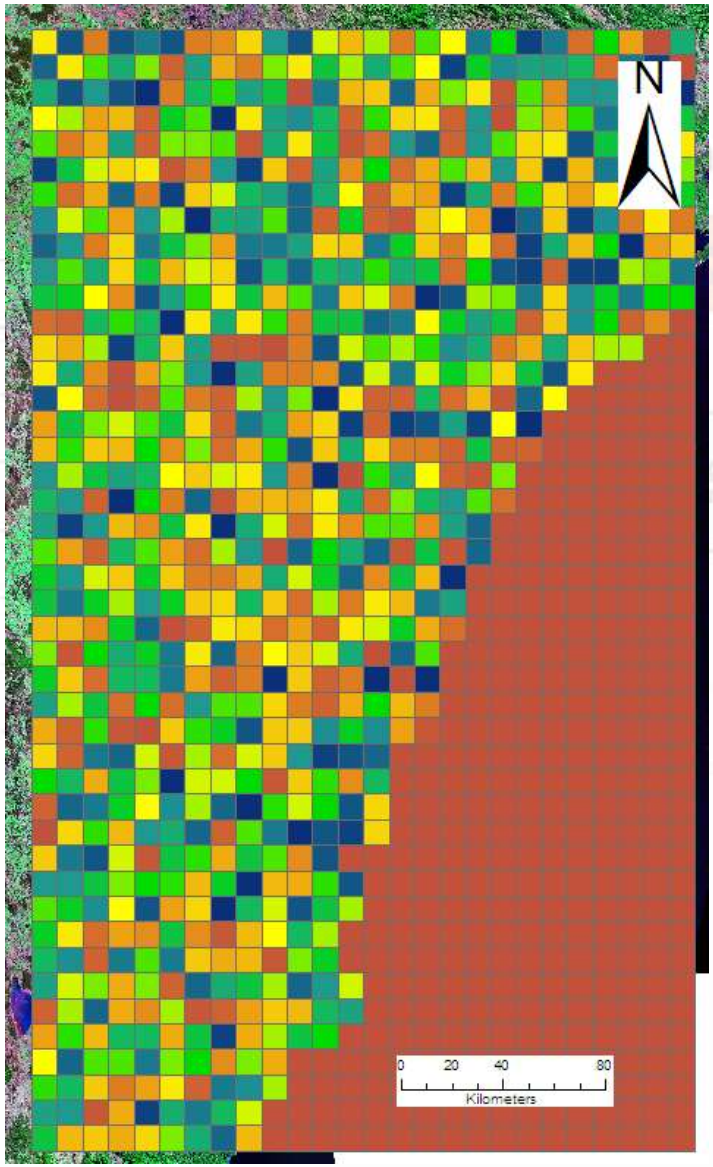
ID	Topography_1	Topography_2	Topography_3	LMZ_D2RD_1	LMZ_D2RD_2	LMZ_D2RD_3	LMZ_D2RD_4	LMZ_house_dens_2km_1	LMZ_house_dens_2km_2	LMZ_house_dens_2km_3
1	0.17131875	0.62344375	0.2052375	0.858125	0.13375	0.008125	0	0.179	0.6036	0.2
2	0.1520875	0.56021875	0.28769375	0.92125	0.075625	0.003125	0	0.1189	0.3258	0.1
3	0.2366375	0.51035625	0.25300625	0.87	0.08875	0.04125	0	0.2002	0.5189	0.1
4	0.20355	0.63	0.1606625	0.340625	0.186875	0.4175	0.055	0.7772	0.2228	
5	0.28450625	0.59	0.12435	0.614375	0.208125	0.175625	0.001875	0.4374	0.4866	0.
6	0.3672375	0.534	0.0982	0.66625	0.215625	0.118125	0	0.6597	0.1998	0.1
7	0.2491125	0.61154	0.13934375	0.80875	0.105625	0.085625	0	0.3333	0.1009	0.2
8	0.26343125	0.54591	0.19065	0.96125	0.0375	0.00125	0	0.1219	0.155	0.4
9	0.1720125	0.422925	0.4050625	0.968125	0.031875	0				0.5
10	0.21128125	0.62093125	0.1677875	0.861875	0.120625	0.0175				0.0
11	0.127075					25	0			0.0
12	0.21315625					25	0			0.
13	0.289025					21	0.08125			0.0
14	0.268975					25	0.454375			
15	0.2992125					25				0.0
16	0.15489375					75				0.3
17	0.19191875					05				0.1
18	0.13581875					75	0			0.
19	0.1817					035	0			0.0
20	0.1382625	0.57901875	0.28271875	0.8325	0.144375	0.023125				0.0
21	0.1919875	0.54269375	0.26531875	0.843125	0.149375	0.0075				0.





- *BN applied to each unit (i.e., row in the input file) in a totally automated fashion (Netica API in Java)*
- *For each run, "spatial" evidences are assigned to the states of all input variables (i.e., parentless nodes) and propagated through the BN to predict the probability of unsuppressable fire of that specific unit*

Data and methods: GIS and BN integration

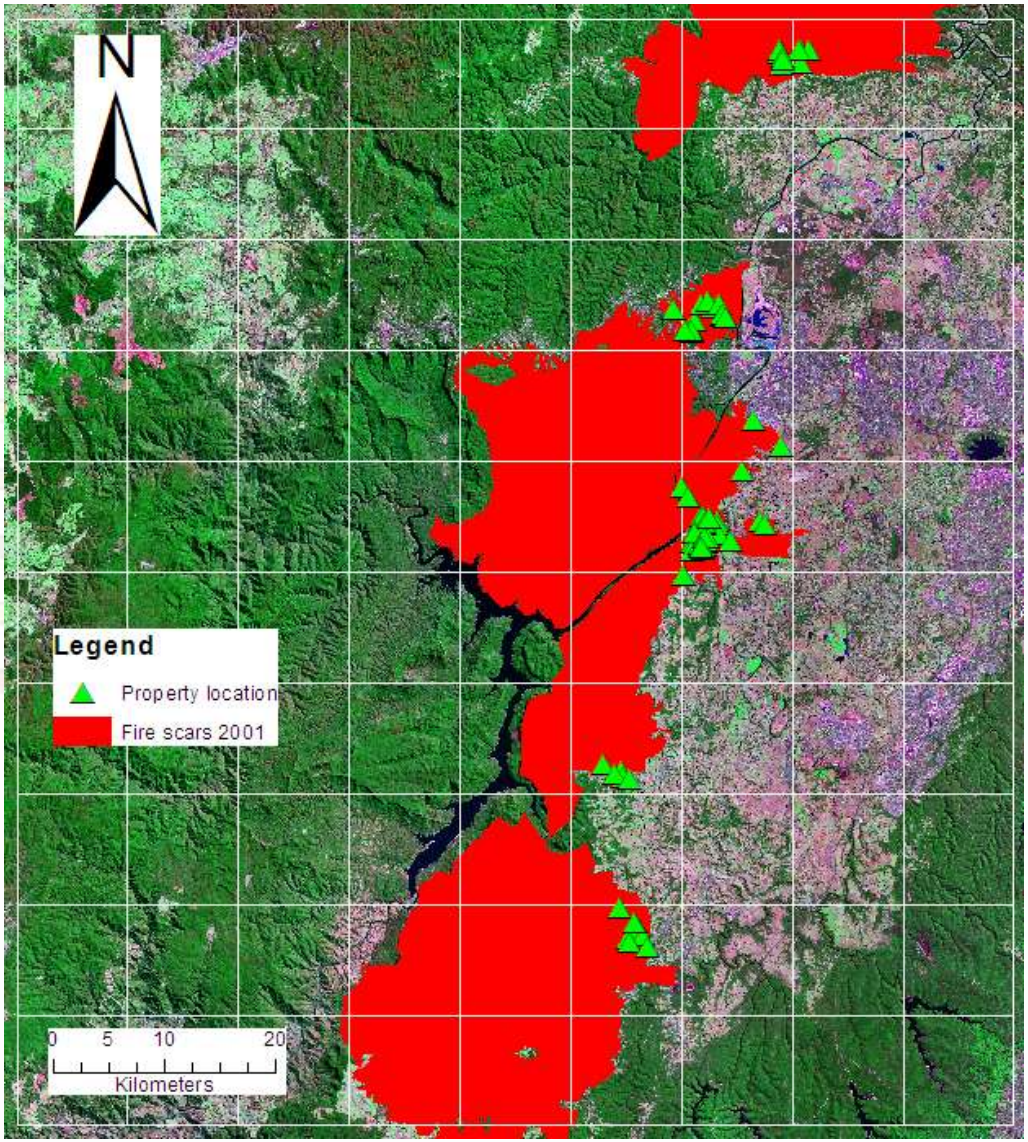


The probability of unsuppressable fires of each unit is finally saved to a geo-referenced GRID which can be accessed, displayed and analysed in GIS environment

Processing speed: 62 seconds for 1144 simulations (tested on Intel(R) Core(TM)2 Duo CPU, 2.66GHz, 3.23 GB RAM)

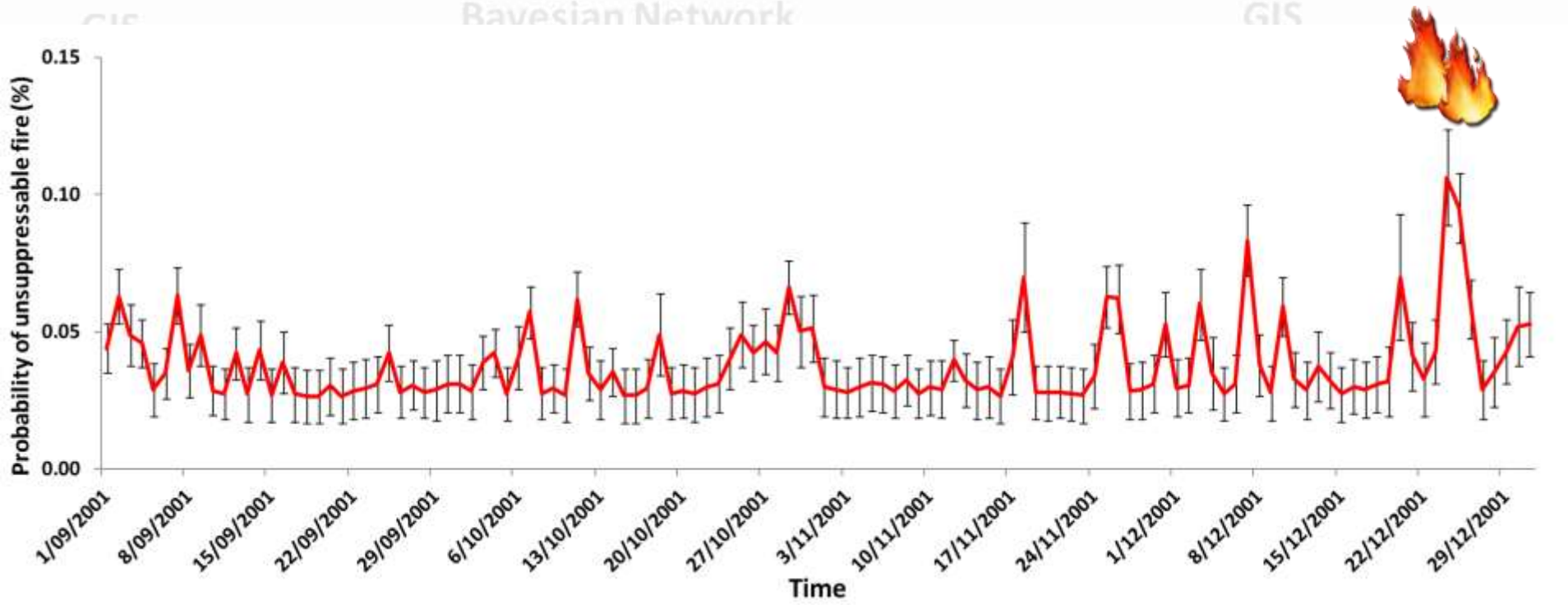
Preliminary testing

Beta-level model → Testing, calibration, sensitivity analysis, etc



- *24/25 December 2001*
- *Over 500,000 ha burnt*
- *Several properties burnt/lost*

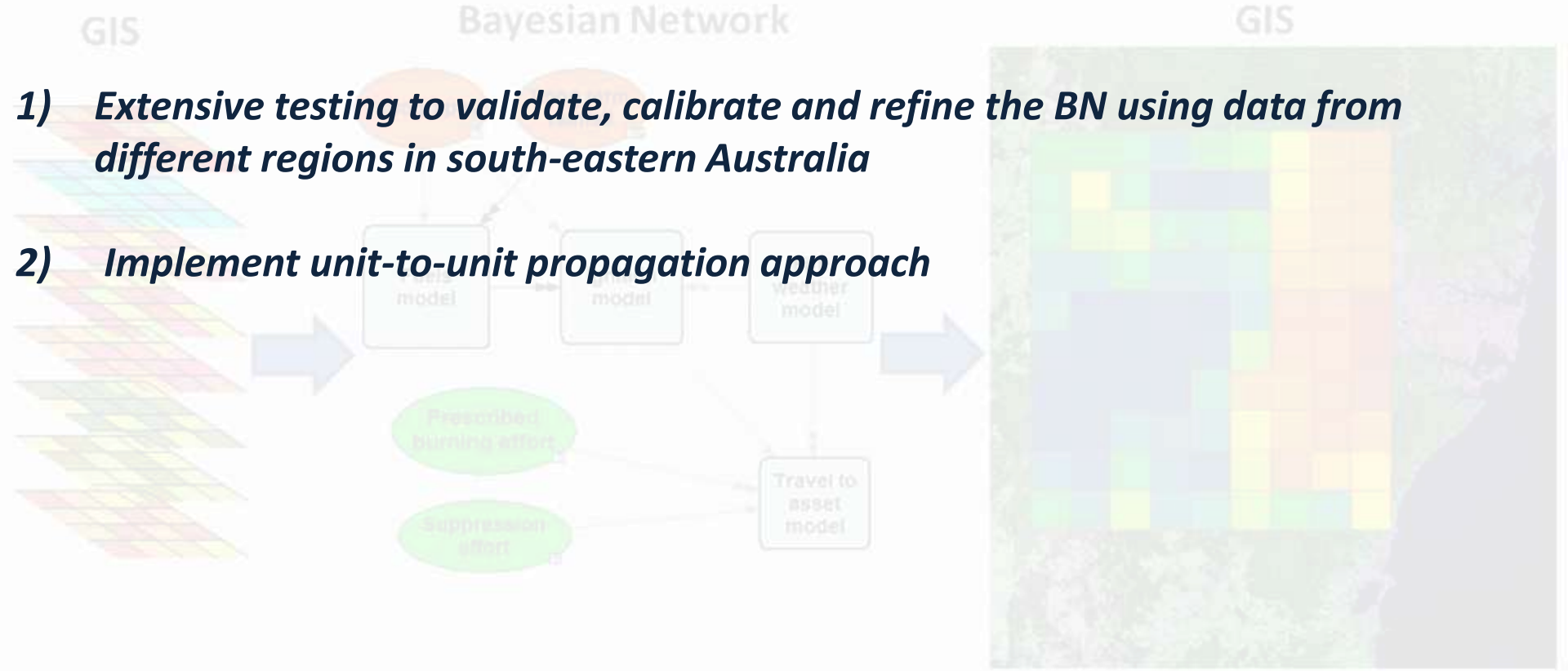
Preliminary testing



What's next?

1) *Extensive testing to validate, calibrate and refine the BN using data from different regions in south-eastern Australia*

2) *Implement unit-to-unit propagation approach*




GIS
Bayesian Network
GIS
Topography
Long term rainfall
Fuels model
Ignition model
Fire weather model
Prescribed burning effort
Suppression effort
Travel to asset model

THANK YOU