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Statistical characterisation of wind fields over complex terrain for bushfire modelling

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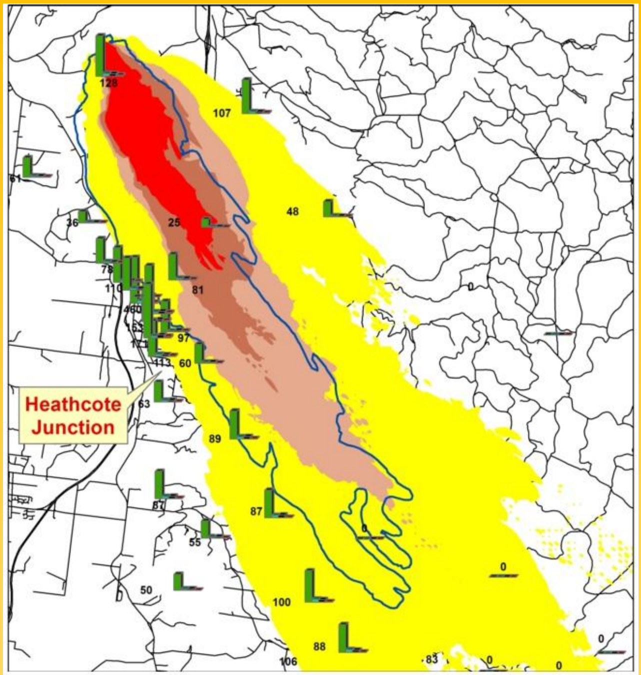
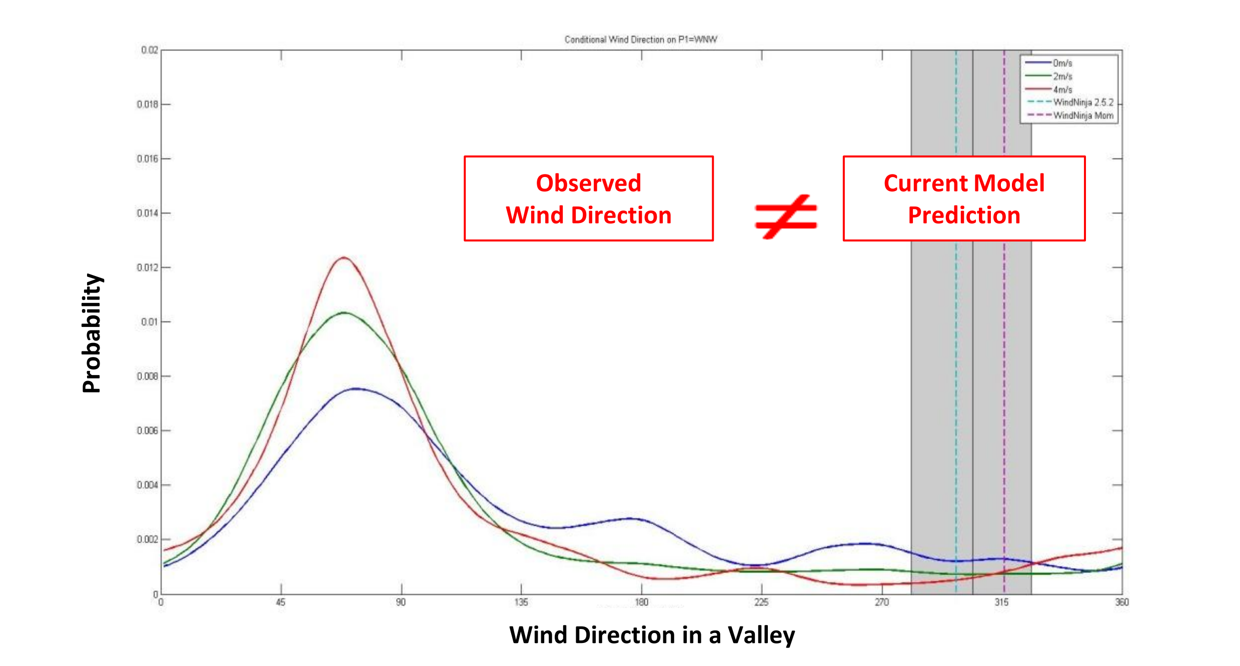
Motivation

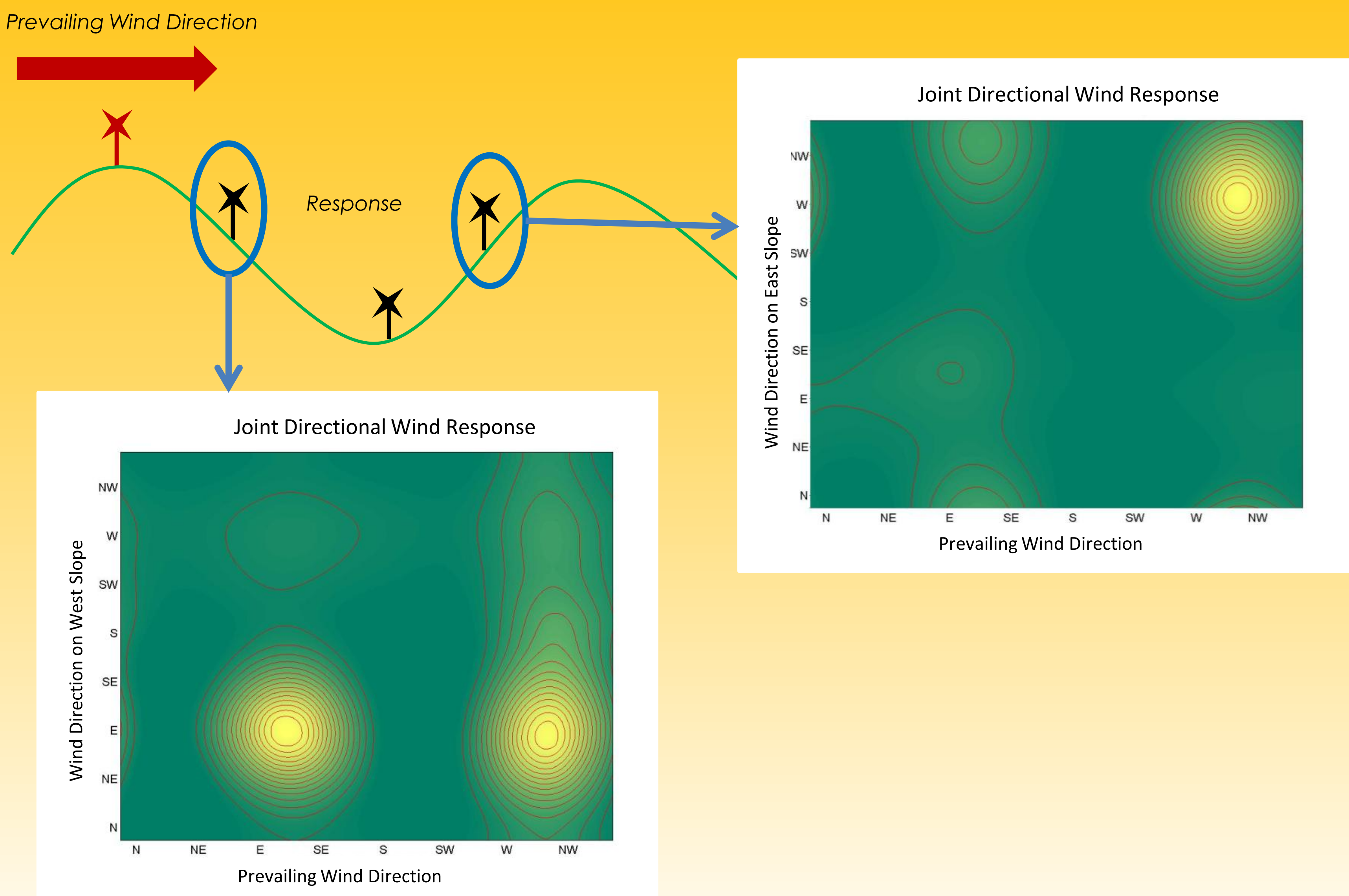
- With emerging ensemble-based fire risk modelling frameworks, it is useful to recast wind in probabilistic terms.
- Probabilistic fire modelling inputs allow for better informed decision making when uncertainties are quantified and accounted for.



Source: French *et al.* (2013)

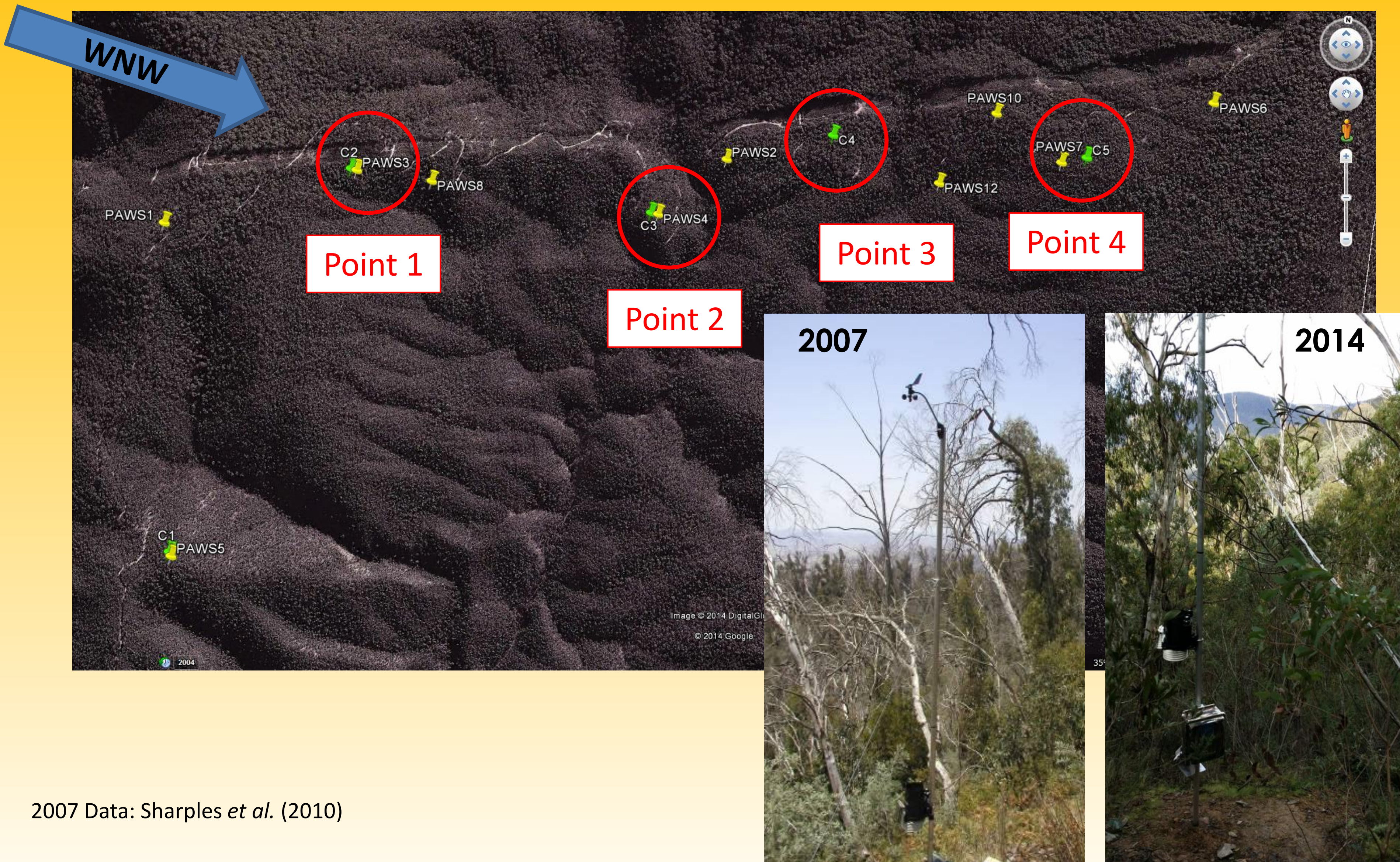


Directional Wind Response



Flea Creek Valley

January to October 2007 and April to December 2014

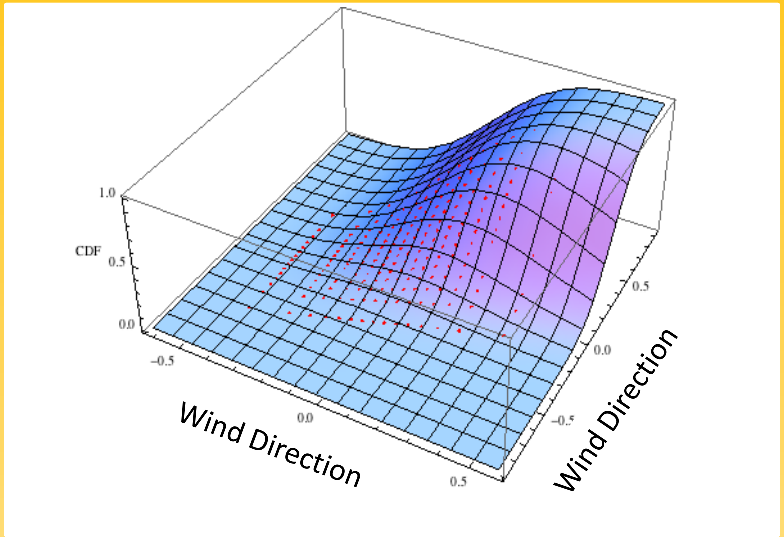


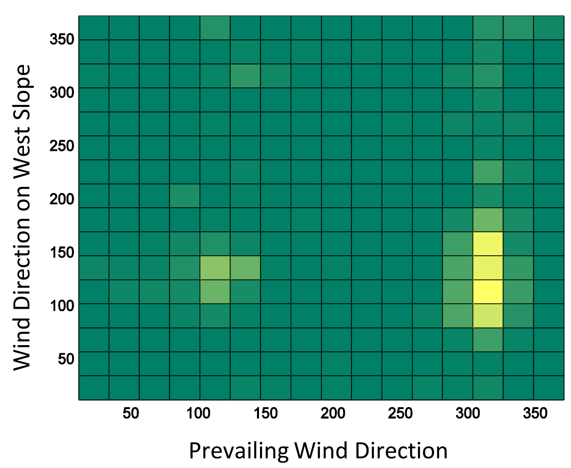
2007 Data: Sharples *et al.* (2010)

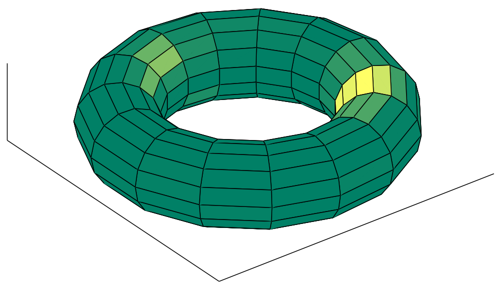
Statistical Comparison Tests

Consider the empirical distributions

- Statistics are based on the maximum difference between the cumulative distributions.
- Further work will consider the adaptation of this statistic to account for circularity.







Kolmogorov-Smirnov Test

- Univariate – maximum difference between the empirical distributions

$$D_n^{(1)} = \sup_x \left| F_X(x) - G_X(x) \right|, \text{ where } F_X(x) = P(X \le x)$$

- Since this is proportional to *n*, an the following alternative is used

$$Z_n^{(1)} = \sqrt{n} D_n^{(1)}, \text{ with } n = \frac{n_1 n_2}{n_1 + n_2}$$

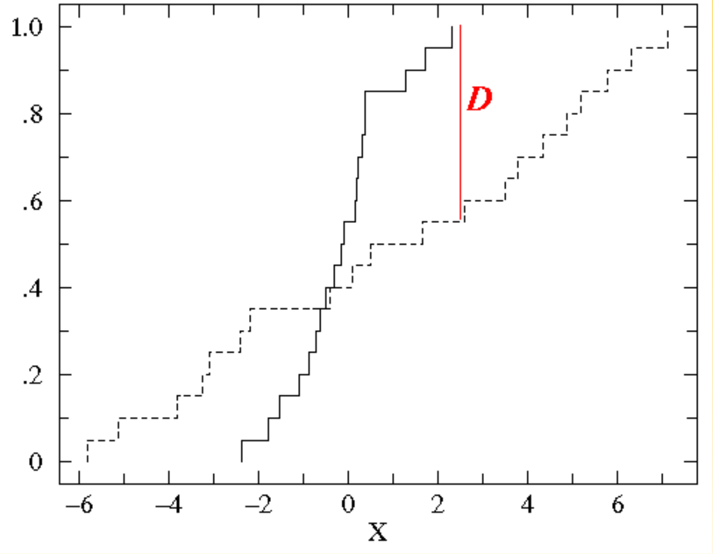
- Critical Values of $D_n^{(1)}$ (Massey, 1951)

$$d_{0.01} = 1.63 / \sqrt{n}, \; d_{0.05} = 1.36 / \sqrt{n}$$

- P-values
  - (Gosset, 1987)

$$P(Z_\infty^{(1)} > z) \simeq 2\exp(-2z^2)$$

  - Monte Carlo simulations (M = 1000)



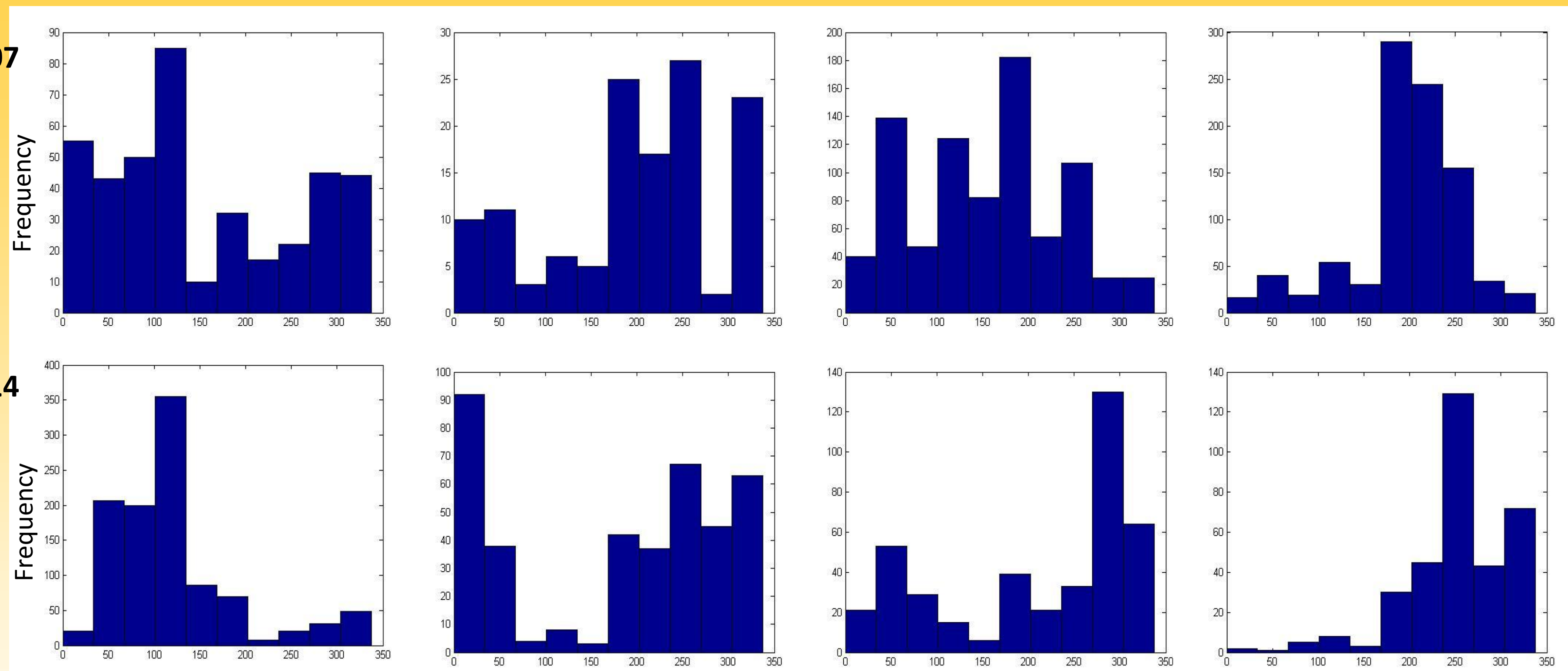
Kolmogorov-Smirnov Test

	n_1	n_2	$D_n^{(1)}$	$d_{0.01}$	$d_{0.05}$	$Z_n^{(1)}$	P_Z	P_Z^m	P_D^m
Point 1	1046	403	0.2259	0.0956	0.0797	3.8529	2.55 E-33	0	0
Point 2	129	399	0.1630	0.1651	0.1377	1.6096	0.0112	0.009	0.001
Point 3	825	411	0.4226	0.0984	0.0821	6.9987	5.7 E-43	0	0
Point 4	903	338	0.4893	0.1057	0.0882	7.6740	1.41 E-51	0	0

Point 1: Leeward Slope **Point 2:** Valley Floor **Point 3:** Windward Slope **Point 4:** Windward Slope

2007

2014



Surface Wind Direction, Conditional on WNW Prevailing Wind Direction

Extended Kolmogorov-Smirnov Test

- With a bivariate joint distribution, we can define the CDF in four directions (Peacock, 1983):

$$Q1 = (X \le x, Y \le y),\ Q2 = (X \le x, Y \ge y),\ Q3 = (X \ge x, Y \le y),\ Q4 = (X \ge x, Y \ge y)$$

- So the bivariate extension of the KS statistic becomes the maximum of the maximum differences between empirical distributions

$$D_n^{(2)} = \max(D_n^{Q1}, D_n^{Q2}, D_n^{Q3}, D_n^{Q4})$$

with $D_n^{Q1} = \sup_{(x,y)} \left| F_{X,Y}^{Q1}(x,y) - G_{X,Y}^{Q1}(x,y) \right|, \text{ where } F_{X,Y}^{Q1}(x,y) = P(X \le x, Y \le y)$

- This is still proportional to *n*, so the following alternative is used

$$Z_n^{(2)} = \sqrt{n} D_n^{(2)}, \text{ with } n = \frac{n_1 n_2}{n_1 + n_2}$$

Extended Kolmogorov-Smirnov Test

- P-values
  - For the area of interest where $P(Z_n^{(2)} > z) \leq 0.2$

  the asymptotic behaviour of the statistic is given by (Peacock, 1983);

$$P(Z_\infty^{(2)} > z) \simeq 2\exp(-2(z-0.5)^2)$$

  - Monte Carlo simulations?

- Critical Values?
  - Peacock (1983) gives critical values for $D_n^{(2)}$ with n = 50;

$$d_{0.01} = 2.06, \; d_{0.05} = 1.83$$

  - But we have much larger sample sizes...

Extended Kolmogorov-Smirnov Test

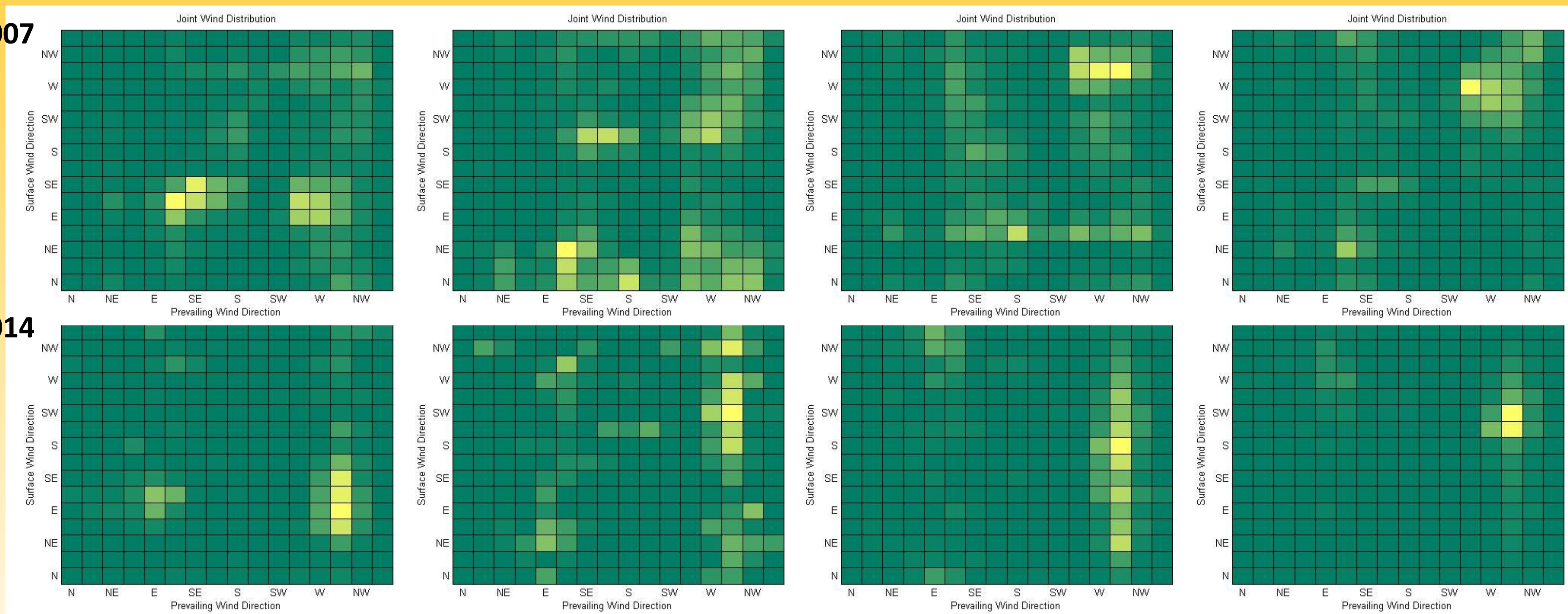
	n_1	n_2	$D_n^{(1)}$	$Z_n^{(1)}$	P_Z
Point 1	2537	2809	0.3309	12.0804	6.58 E-117
Point 2	346	2823	0.2931	5.1466	3.53 E-19
Point 3	1676	2964	0.4574	14.9673	3.19 E-182
Point 4	1864	2161	0.4617	14.6070	2.79 E-173

For $n = 50$,
$d_{0.01} = 2.06$,
$d_{0.05} = 1.83$.

Point 1: Leeward Slope **Point 2:** Valley Floor **Point 3:** Windward Slope **Point 4:** Windward Slope

2007

2014



Discrete Observed Joint Wind Direction Distributions

Kuiper's Test

- Accounts for circularity (Kuiper, 1960)

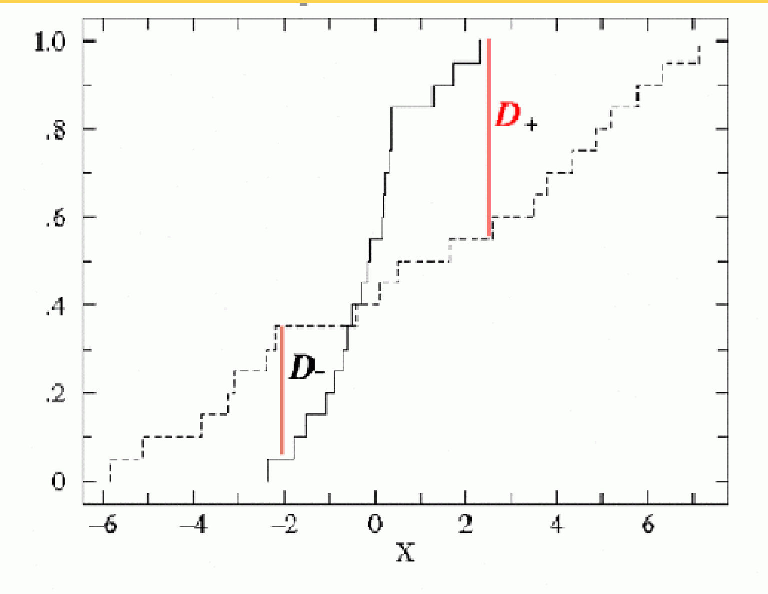
$$V_n^{(1)} = \sup_x \{F_X(x) - G_X(x)\} - \left| \inf_x \{F_X(x) - G_X(x)\} \right|$$

- Extension to Bivariate as in KS?

$$V_n^{(2)} = \max_i (V_n^{Qi}), \text{ or}$$

$$V_n^{(2)} = \max_i (V_n^{Qi}) - \min_i (V_n^{Qi}) \ ?$$

- P-values and critical values...



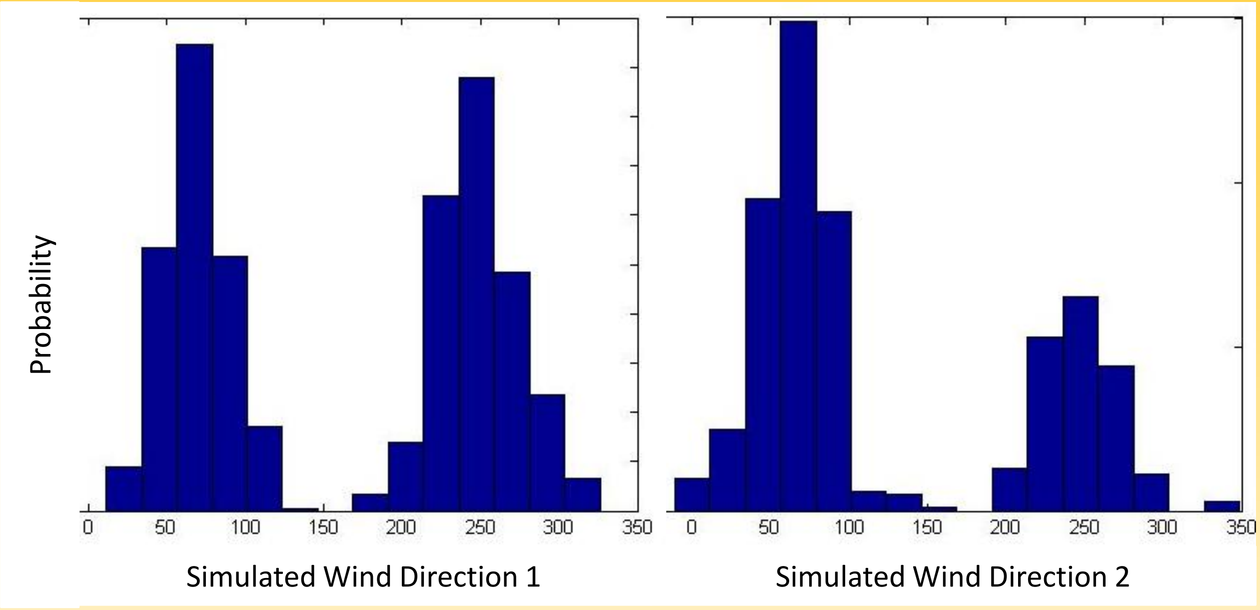
<u>**HOW**</u> has the vegetation altered the wind fields across Flea Creek Valley?

(1) Evaluate the sensitivity of the tests using simulation studies

(2) Consider a more controlled experiment

Sensitivity Evaluation

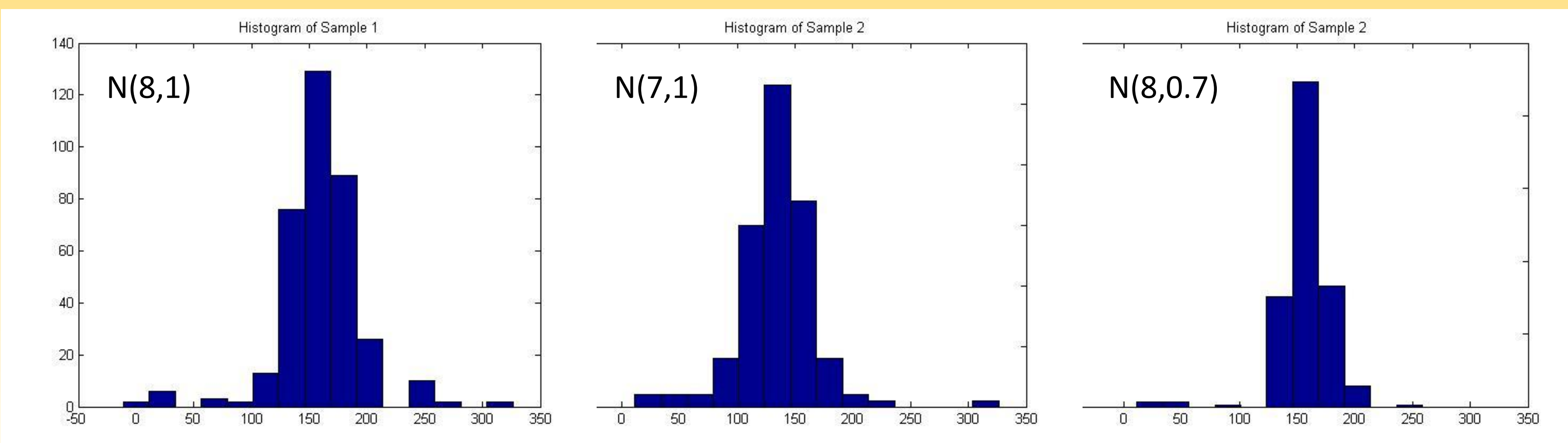
How big does a change in the distribution need to be to cause a significant test result?



Sensitivity Evaluation

Initial univariate, uni-modal results for Normal distribution

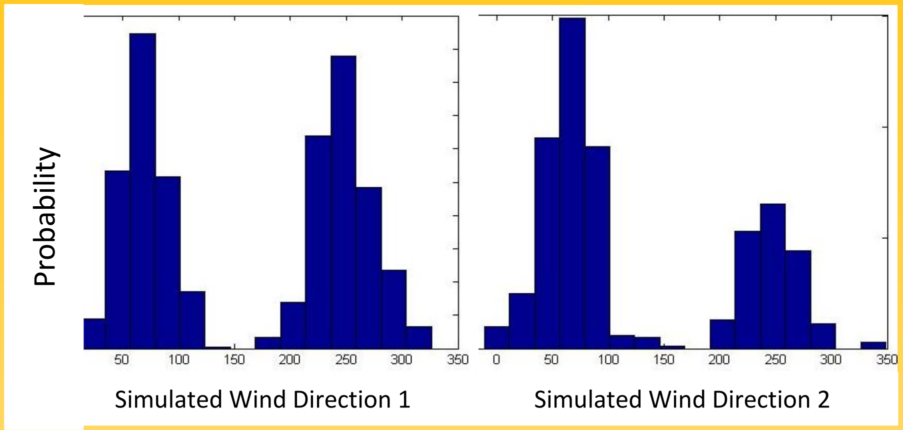
Model 1	Model 2	n_1	n_2	$D_n^{(1)}$	$d_{0.01}$	$d_{0.05}$	$Z_n^{(1)}$	P_Z	P_Z^m	P_D^m
N(8,1)	**N(7,1)**	706	837	0.3713	0.0833	0.0695	7.2669	2.71 E-46	0	0
	N(7.5,1)	277	604	0.1973	0.1183	0.0987	2.7196	7.53 E-07	0	0
	N(8,1)	678	485	0.0344	0.0969	0.0809	0.5780	0.8920	0.3530	0.3450
	N(8.5,1)	852	561	0.1976	0.0886	0.0739	3.6342	6.75 E-12	0	0
	N(9,1)	624	1048	0.3978	0.0824	0.0688	7.8680	3.4 E-54	0	0
N(8,1)	**N(8,0.9)**	968	905	0.0261	0.0754	0.0629	0.5639	0.9082	0.3870	0.3870
	N(8,0.8)	755	1007	0.0613	0.0785	0.0655	1.2752	0.0778	0.0080	0.0080
	N(8,0.75)	458	917	0.1083	0.0933	0.0778	1.8934	0.0015	0	0
	N(8,0.5)	640	965	0.2042	0.0831	0.0693	4.0054	2.32 E-14	0	0



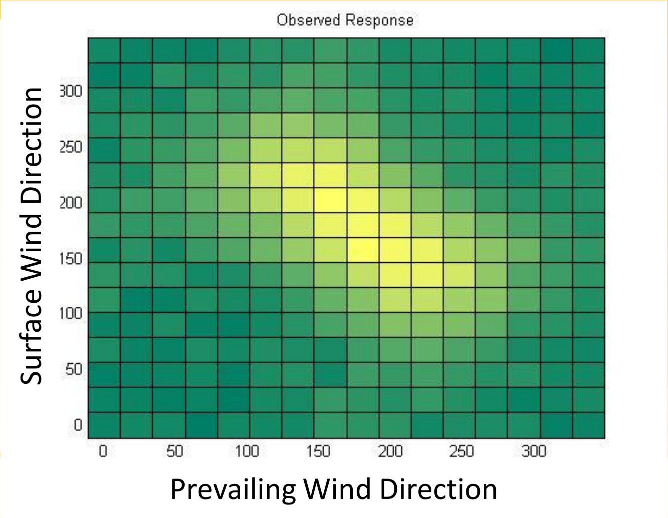
Sensitivity Evaluation

<u>Continuing Work</u>

- Univariate distributions
  - Bi-modal
  - Circular

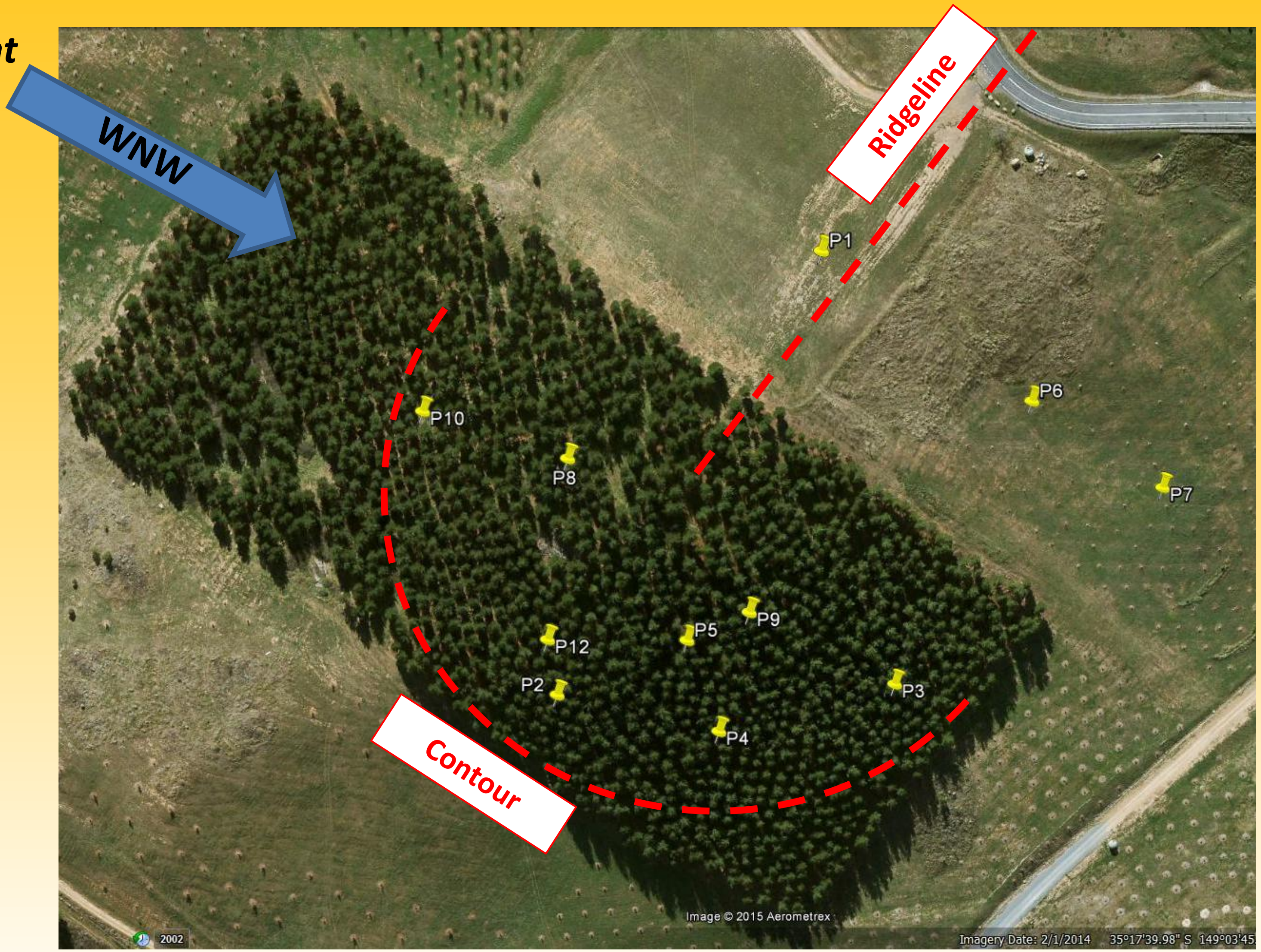


- Bivariate distributions
  - Bivariate Normals,
  - Wrapped Normals or von Mises
  - Mixtures for multimodal distributions

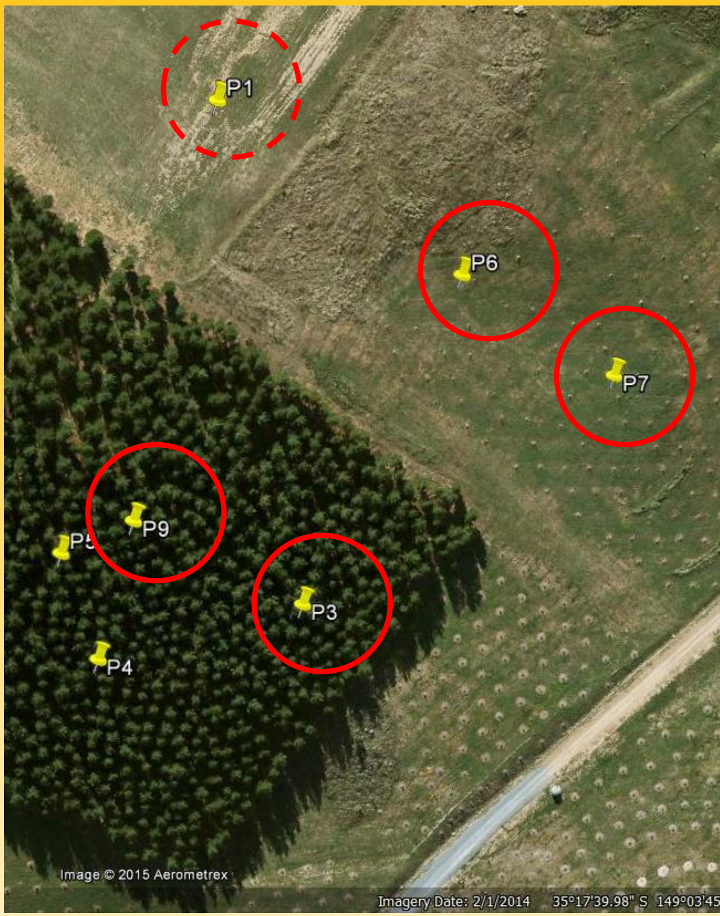


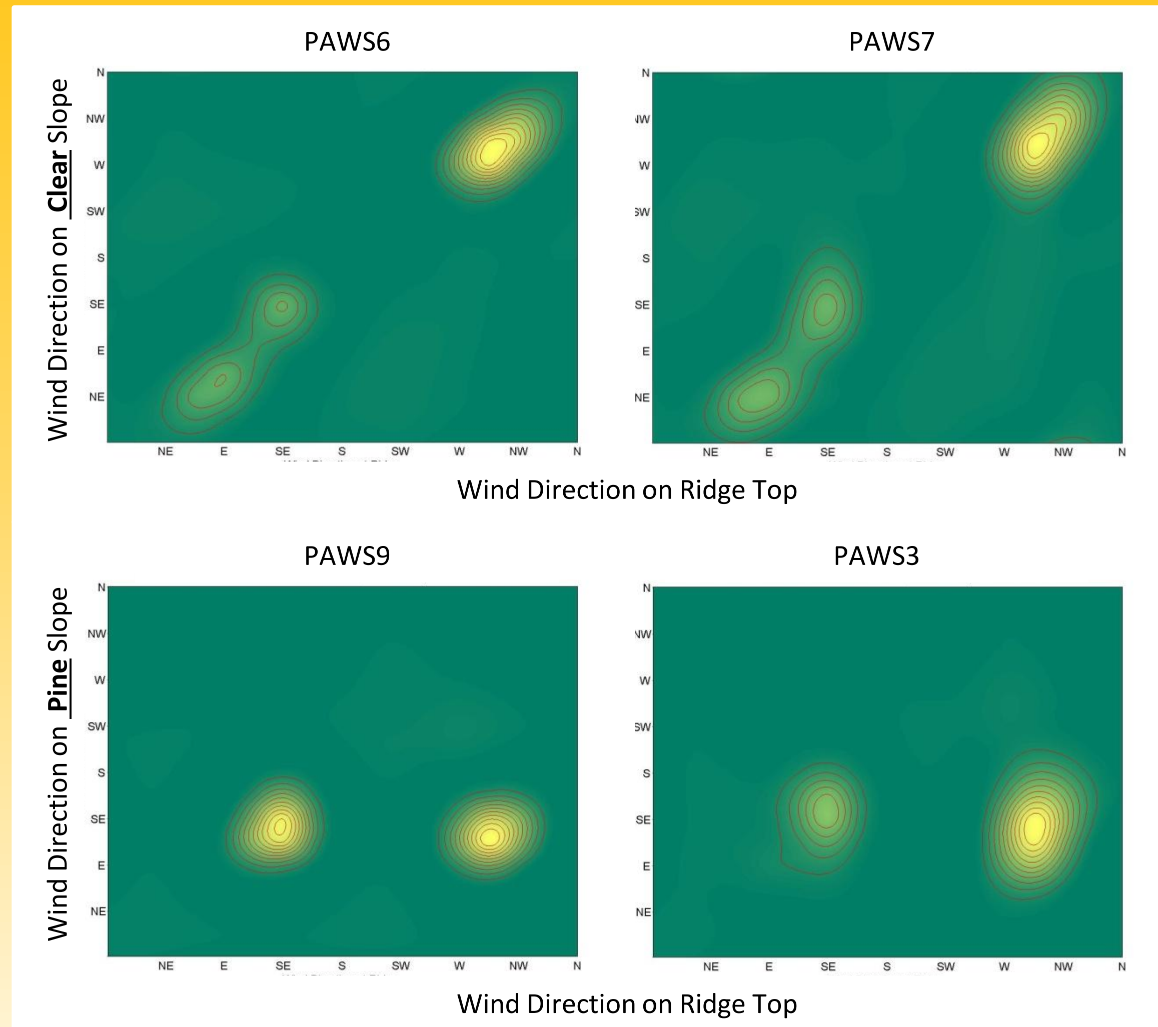
Controlled Study: National Arboretum Canberra

April 2015 to Present

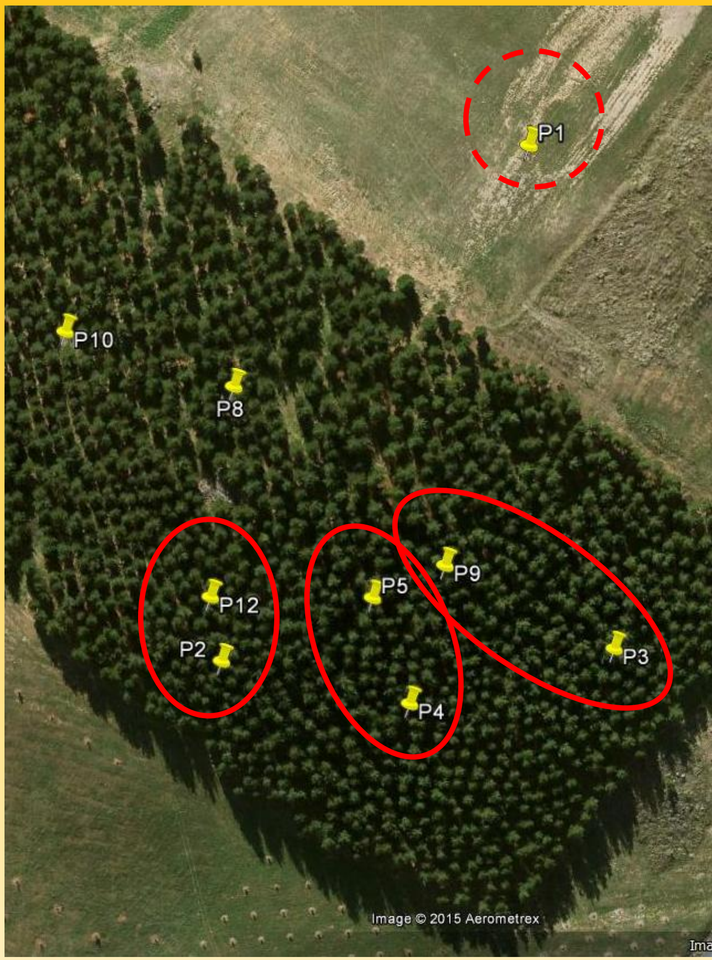


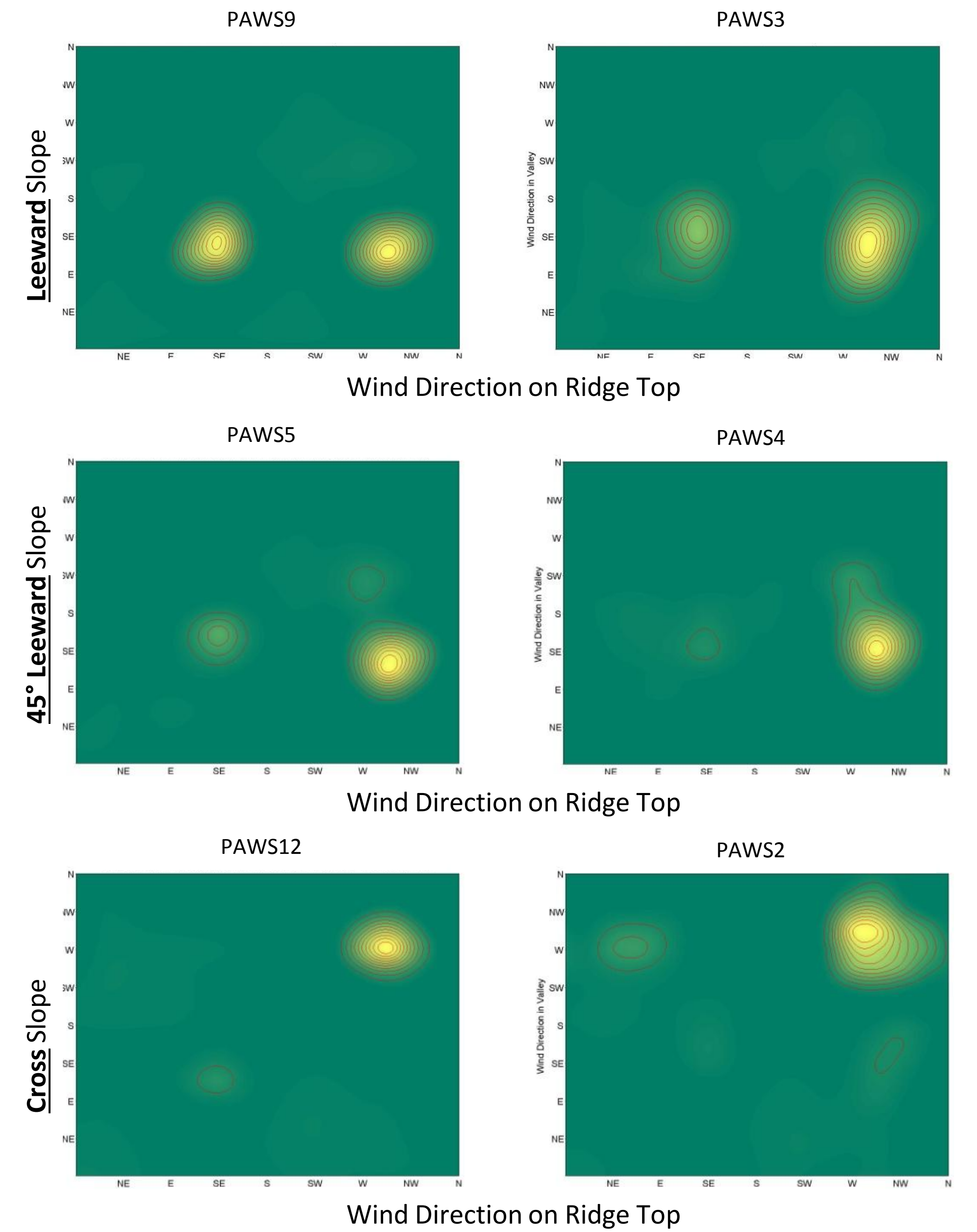
NAC: Changes in Vegetation





NAC: Changes in Topography





Further Work

- Continue and extend investigations to allow better physical interpretation of results in relation to wind fields.
- Consideration of the impacts of vegetation on wind speeds, not just wind directions.
- Evaluate current operational models using observed data.

Consider the potential for **hybrid probabilistic approach** to wind modelling for bushfire applications.

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Thank you

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