From:	John Schmuck
To:	Lancaster, Thomas; Stutzcage, Edward; Burrows, Ronald
Cc:	Larry McGonagle; Doug Pavlick; Larry Teahon; Rhonda Grantham
Subject:	NMA Workshop Presentation - Statistical Analysis of Long Term Weather Trends
Date:	Wednesday, August 06, 2014 1:32:16 PM
Attachments:	Ronn Smith 2014 NMA Workshop Meteorology Presentation.pdf

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Tom - As we discussed, I am providing this for your information.

Thanks. .john

Evaluation of Alternative Methods to Demonstrate Long-Term Representativeness of Baseline-Period Meteorological Monitoring at In-Situ Uranium Recovery Sites

Presentation Outline

- Purpose of Meteorological Data at ISR Sites
- Regulatory Background and History
- Use of Linear Regression Analysis
- Use of Significance Testing
- Conclusions and Qualifications

Purpose of Met Data and Long-Term Representativeness

- Support baseline period and operational air monitoring
- Support dispersion modeling (MILDOS) for estimating radiological impacts from airborne emissions (STAR file)
- Support holding pond design and permitting
- Name of the game: minimize uncertainty

Meteorological Parameters

- Temperature, Relative Humidity
- Solar Radiation, Precipitation, Evaporation
- ***Wind Speed, Wind Direction***
- ***Atmospheric Stability Class (turbulence)***
- Speed, Direction and Stability Class are converted to Relative Frequency Distributions (% of time in each category)

Regulatory Guidance

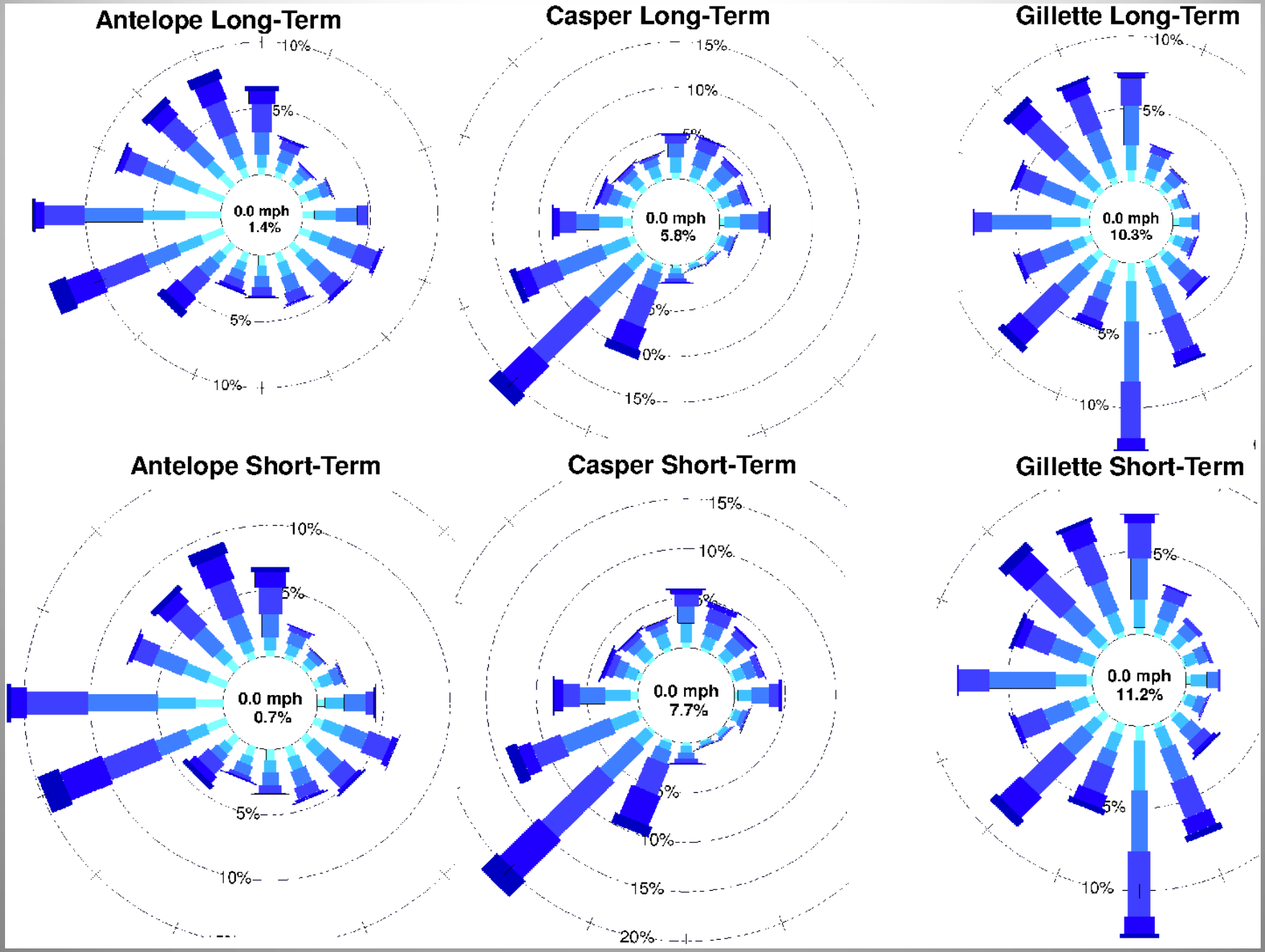
- NRC Regulatory Guide 3.63: On-Site Meteorological Measurement Program for Uranium Recovery Facilities
- NRC NUREG-1475: Applying Statistics
- EPA On-Site Meteorological Program Guidance for Regulatory Modeling Applications

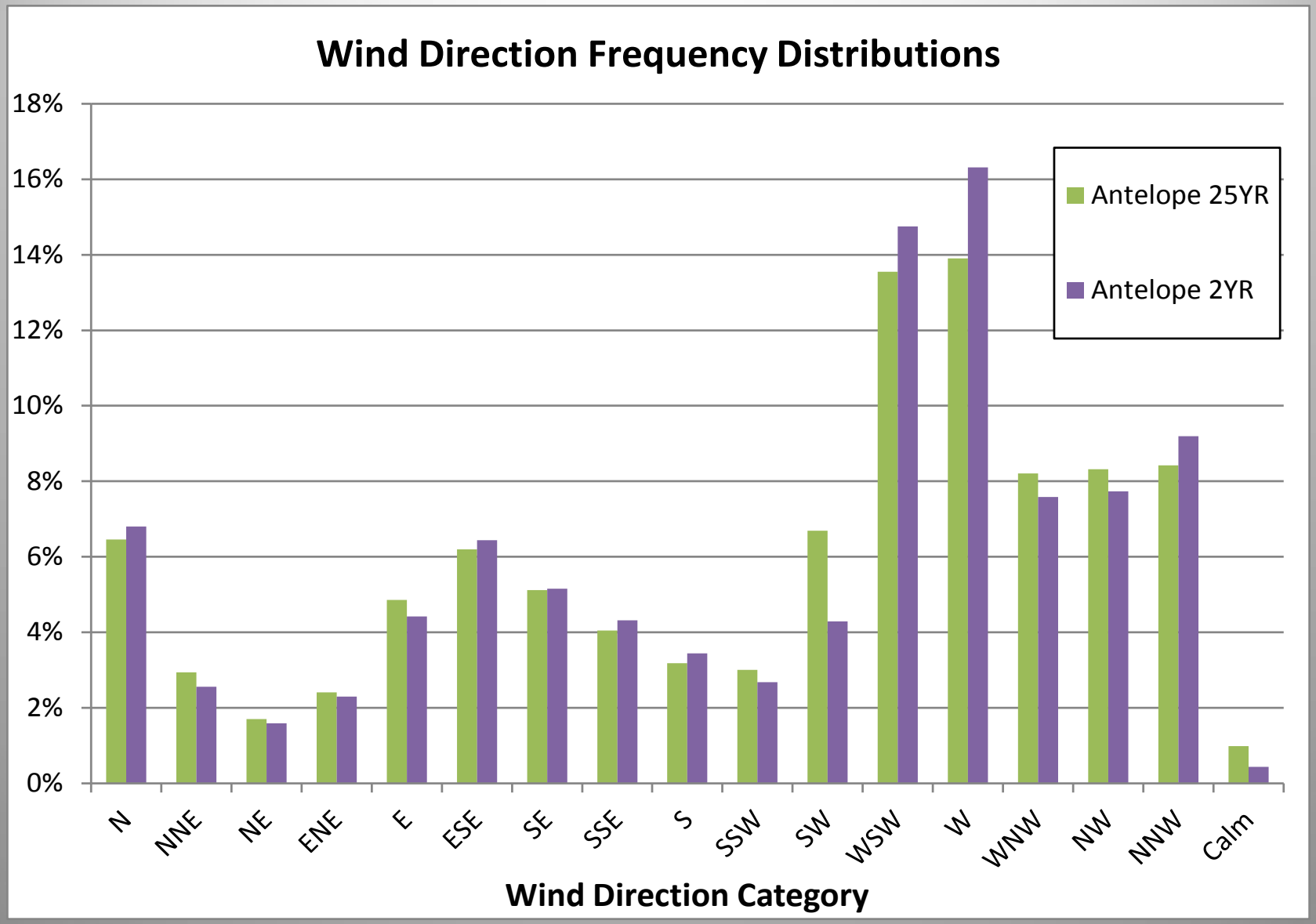
Trends in NRC Acceptance Criteria

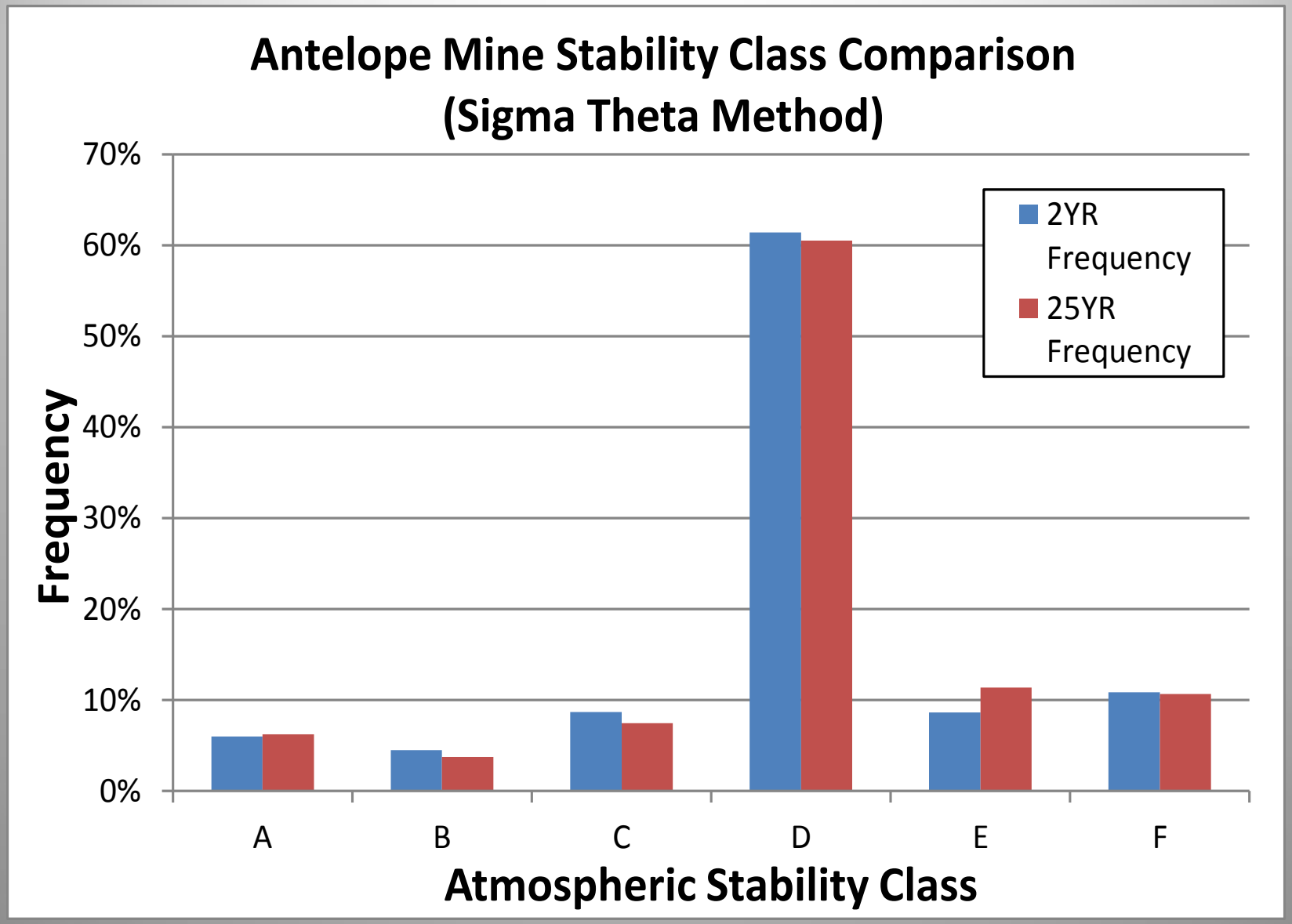
- Increasing requirement for on-site baseline monitoring
- Increasing burden of proof for long-term representativeness of baseline monitoring period
- Closer scrutiny of period of record for long-term, off-site meteorological data
- Shift from qualitative or graphical methods for demonstrating similarity, to more objective statistical methods to compare wind and stability class frequency distributions

Graphical Methods

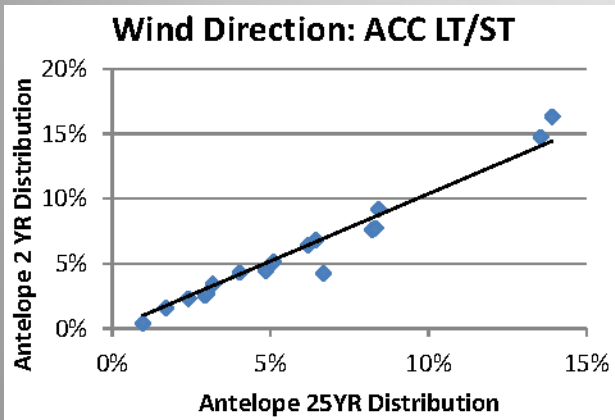
- Long-Term (LT) and Short-Term (ST) Wind Rose Comparison
- Histogram of LT and ST Wind Speed, Wind Direction, and Stability Class Frequency Distributions
- Scatter Plots of LT vs. ST Frequencies

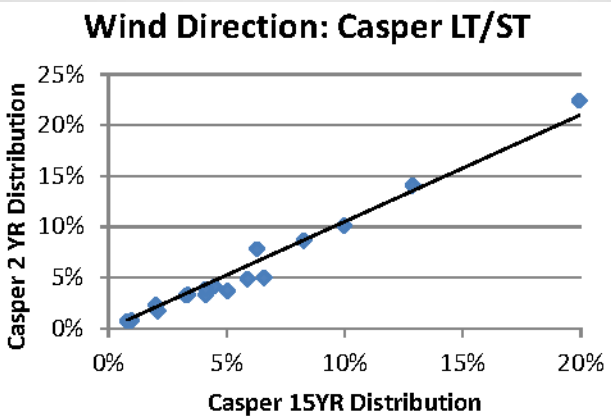

Antelope Long-Term
10%
5%
0.0 mph
1.4%
5%
10%
Casper Long-Term
15%
10%
5%
0.0 mph
5.8%
5%
0%
15%
Gillette Long-Term
10%
5%
0.0 mph
10.3%
5%
10%
Antelope Short-Term
10%
5%
0.0 mph
0.7%
5%
10%
Casper Short-Term
15%
10%
5%
0.0 mph
7.7%
5%
10%
15%
20%
Gillette Short-Term
5%
0.0 mph
11.2%
5%
10%

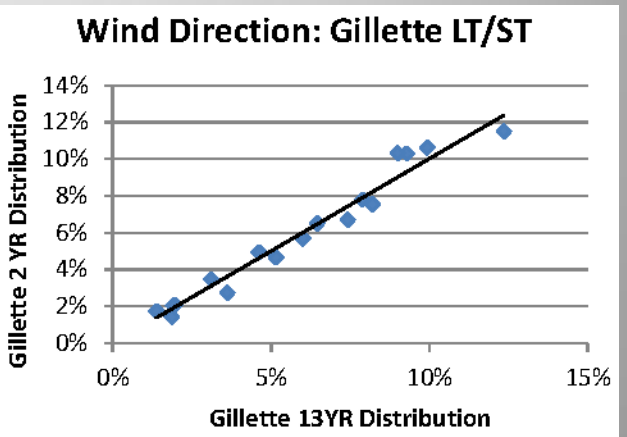

Wind Direction Frequency Distributions
18%
16%
14%
12%
10%
8%
6%
4%
2%
0%
Antelope 25YR
Antelope 2YR
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
Calm
Wind Direction Category

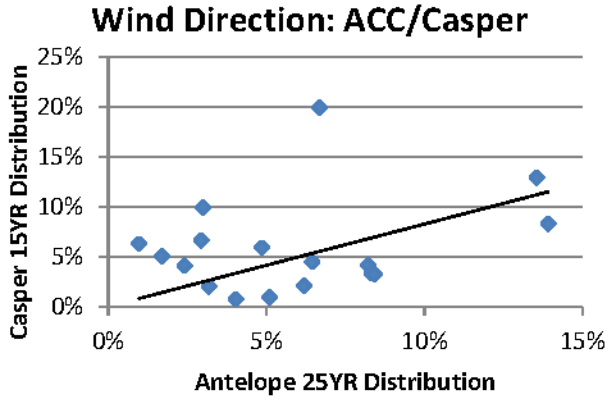

Antelope Mine Stability Class Comparison
(Sigma Theta Method)
70%
60%
50%
40%
30%
20%
10%
0%
Frequency
2YR Frequency
25YR Frequency
A
B
C
D
E
F
Atmospheric Stability Class

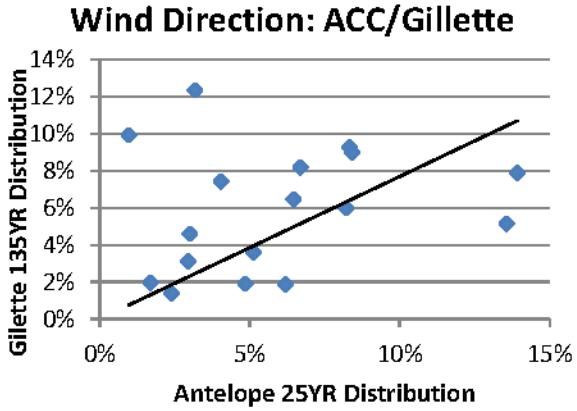
Scatter Plots: Temporal and Spatial Comparisons

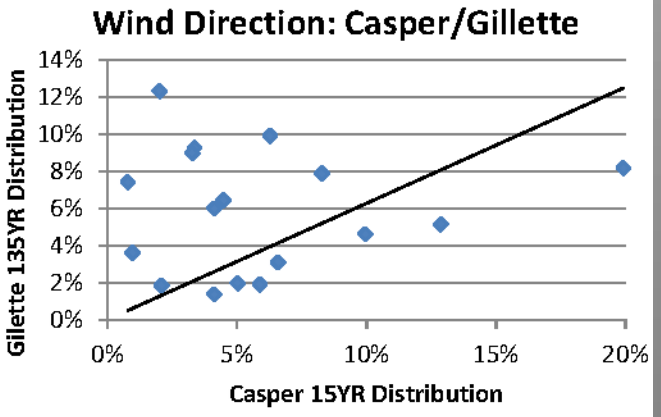








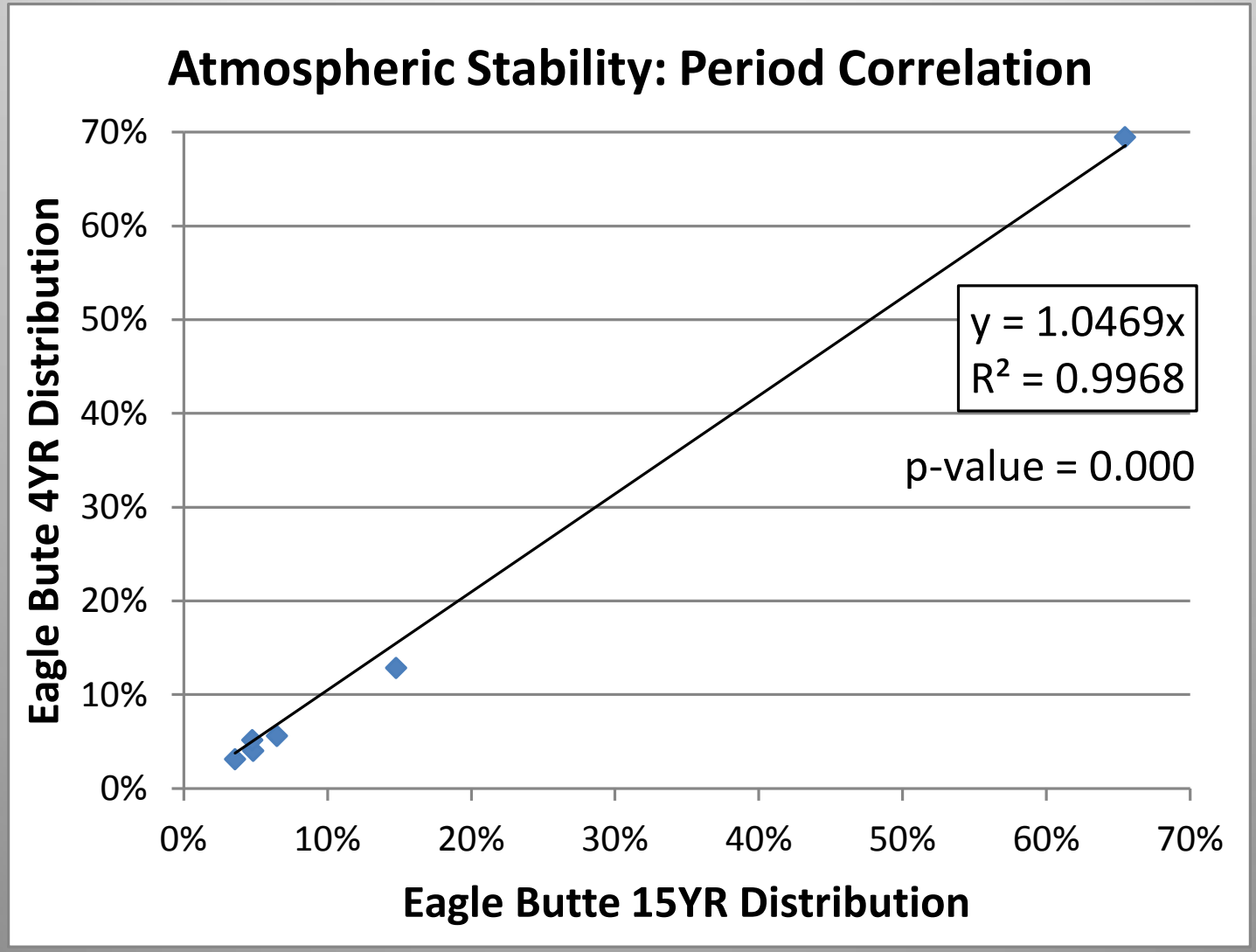




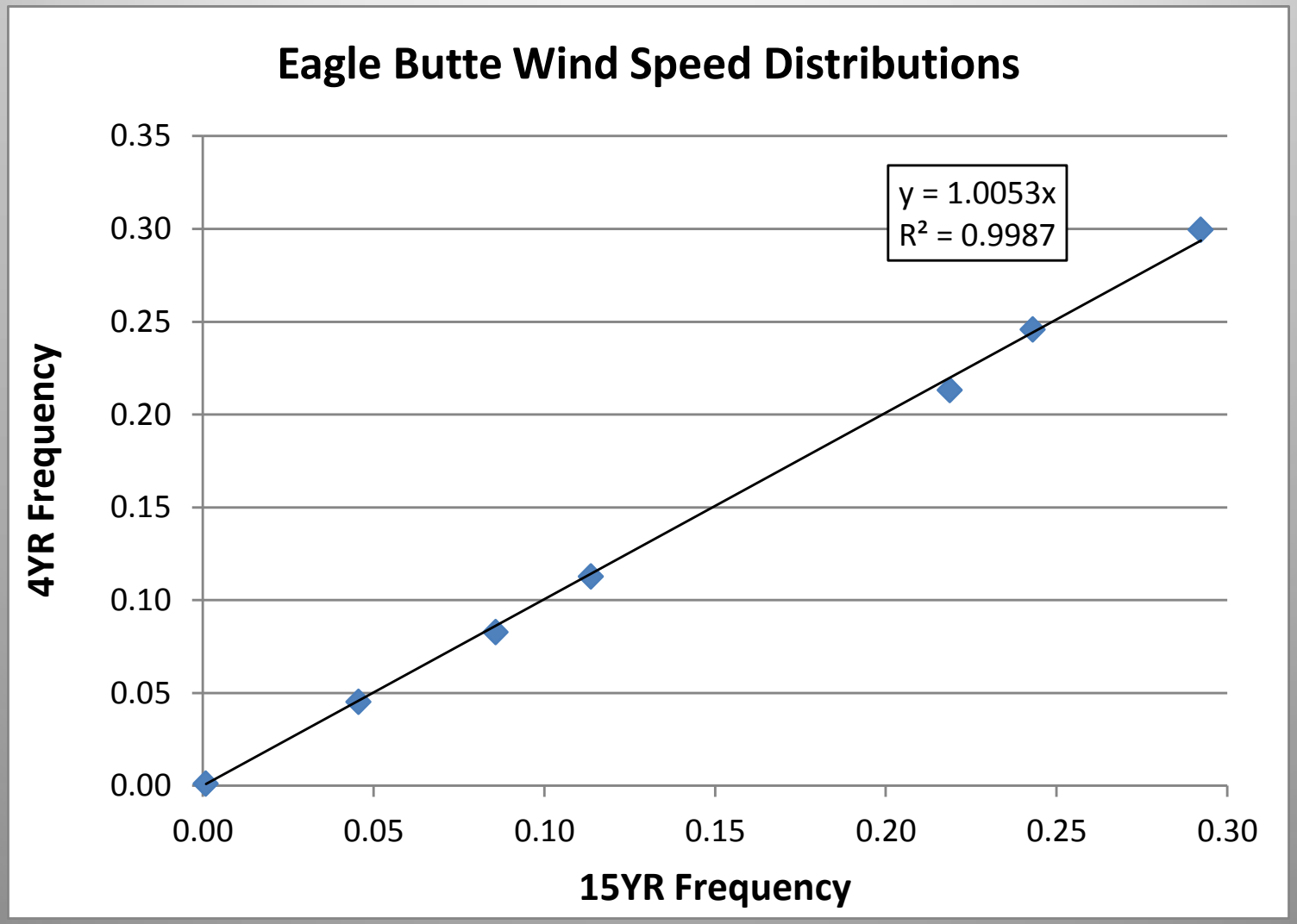
Statistical Methods

- Linear Regression Analysis of Frequency Distributions
- Significance Testing of Frequency Distributions and the Null Hypothesis

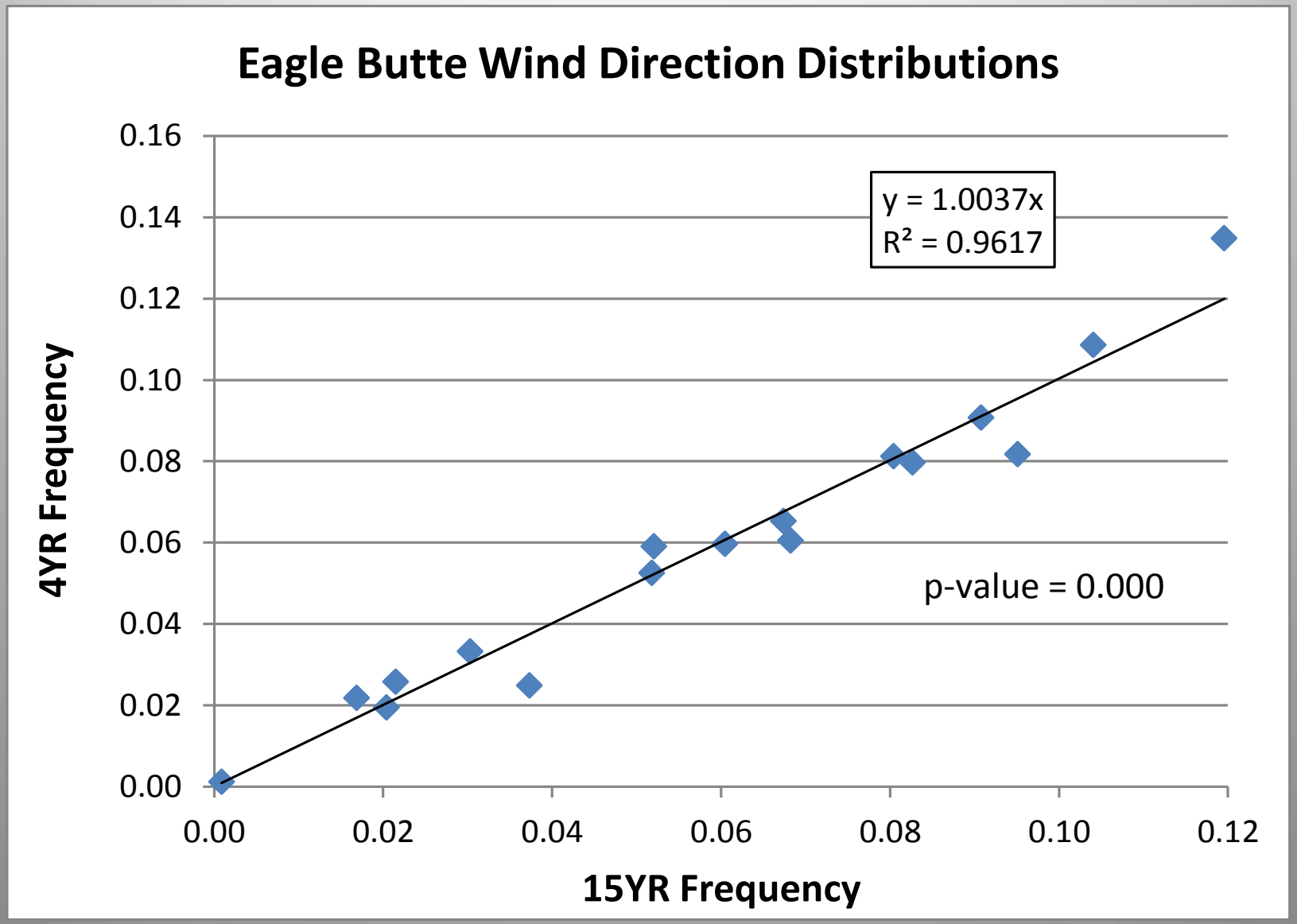
Linear Regression: Stability Class



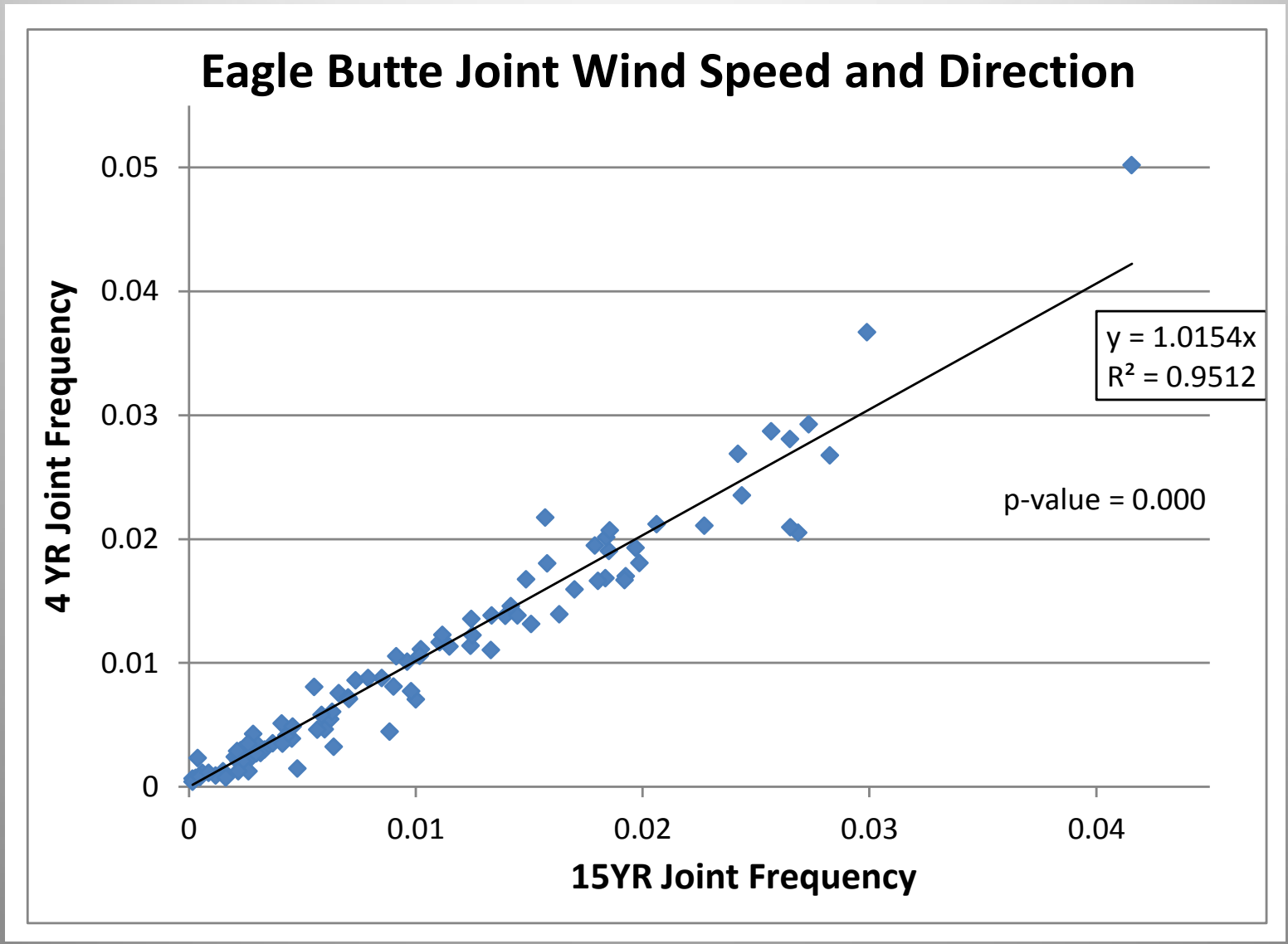
Linear Regression: Wind Speed



Linear Regression: Wind Direction

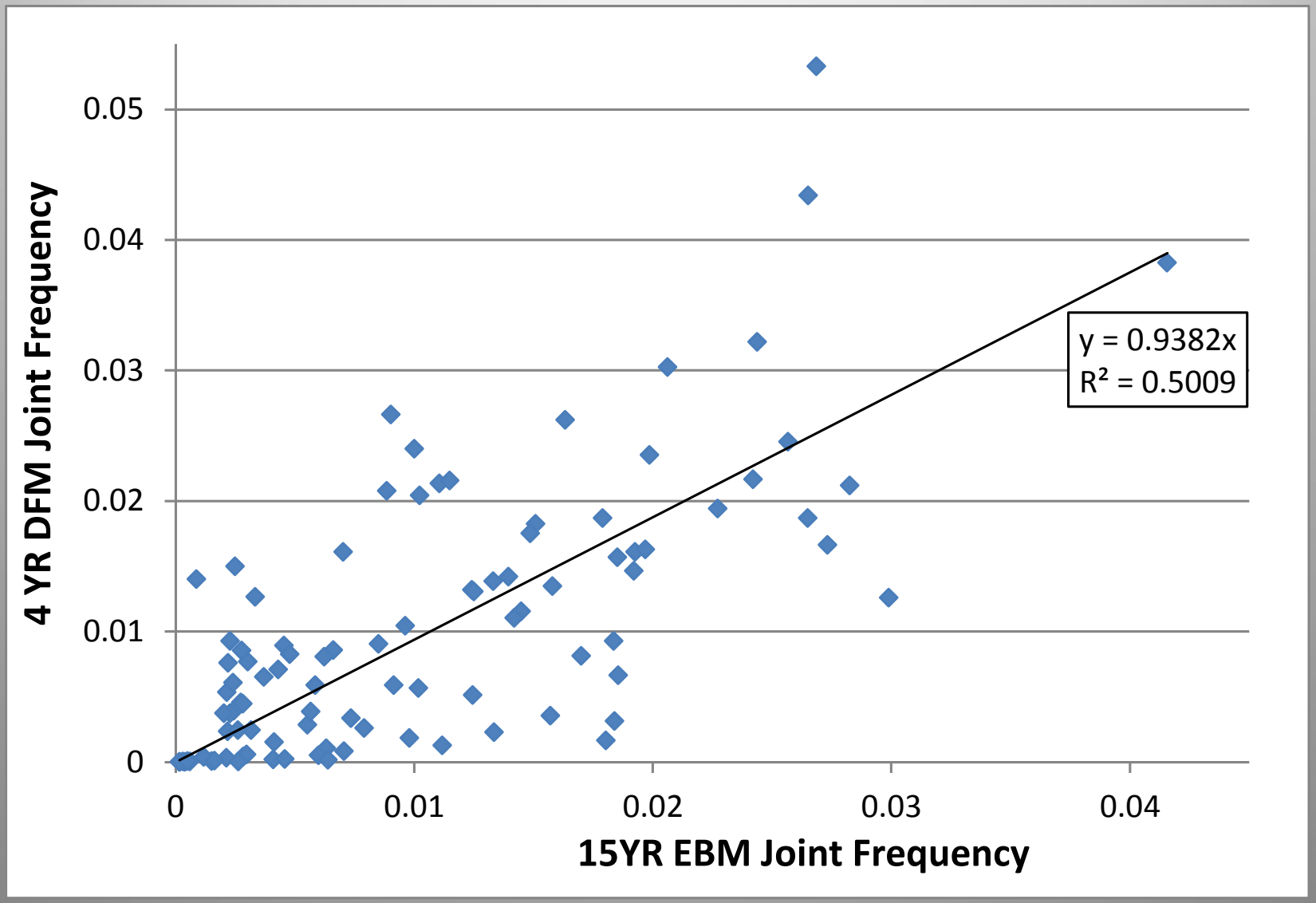


Linear Regression: Joint Wind Speed and Direction Frequency (JFD)



Linear Regression: Dissimilar JFDs

Eagle Butte and Dry Fork Mines (4 miles apart)



Discriminating Power of Linear Regression

Wind Direction Distributions			
Site	R^2	Paired Sites	R^2
ACC LT/ST	0.953	ACC-Csp	0.082
Csp LT/ST	0.971	ACC-Gil	0.036
Gil LT/ST	0.964	Csp-Gil	0.003

Joint Wind Speed and Direction Distributions			
Site	R^2	Paired Sites	R^2
ACC LT/ST	0.921	ACC-Csp	0.155
Csp LT/ST	0.944	ACC-Gil	0.174
Gil LT/ST	0.963	Csp-Gil	0.278

Characteristics of Linear Regression

- Excels at demonstrating similarities
- Differentiates reliably between similar and dissimilar wind patterns
- Measures strength of association (R^2) between LT and ST frequency distributions
- Allocates sources of variation within frequency distributions, between predictable (R^2) and random ($1 - R^2$) components
- Is insensitive to sample size and data categorization

Chi-Square (χ^2) Test

Sums relative squared differences between observed and expected occurrences over all categories. Evaluates Null Hypothesis (H_0) that two distributions are statistically the same (usually rejects H_0 for large samples such as hourly observations over a year, but can adjust for sample size).

Wind Speeds - ACC Annual Hours				
mph	25-Yr WS	2-Yr WS	$(ST-LT)^2/LT$	Chi-Square
0 - 3	1063	931	17	71
4 - 7	2127	1993	8	$\chi^2_{0.95}(6) = 12.59$
8 - 12	2374	2462	3	**Reject H_o**
13 - 18	1778	1902	9	p-value = 0.000
19 - 24	807	871	5	Min Count = 86
> 24	524	563	3	**Phi-value = 0.09**
Calm	86	38	27	

Chi-Square: Wind Direction

Wind Directions - ACC Annual Hours				
Sector	ACC 25Yr WD	ACC 2Yr WD	$(ST-LT)^2/LT$	Chi-Square
N	566	596	1.63	180
NNE	258	224	4.37	$\chi^2_{0.95}(16) = 26.30$
NE	149	139	0.65	**Reject H_o**
ENE	211	201	0.48	p-value = 0.000
E	426	387	3.54	Min Count = 86
ESE	543	564	0.83	**Phi-value = 0.14**
SE	448	452	0.02	
SSE	354	378	1.59	
S	279	302	1.94	
SSW	263	234	3.24	
SW	586	376	75.11	
WSW	1,187	1,292	9.27	
W	1,218	1,430	36.62	
WNW	719	664	4.20	
NW	729	677	3.68	
NNW	738	805	6.25	
Calm	86	38	26.56	

Student's t-test

For each category, evaluates differences between distributions from two periods relative to variations within each distribution: p-value of 0.05 produces 95% confidence that distributions are statistically different

Speed (mph)	25YR Mean	25YR Stdev	2YR Mean	2YR Stdev	Stdev-Pooled	T-Statistic	P-Value
0 - 3	0.1210	0.0173	0.1062	0.0005	0.0170	1.18	0.248
4 - 7	0.2418	0.0331	0.2275	0.0088	0.0325	0.60	0.555
8 - 12	0.2706	0.0183	0.2810	0.0119	0.0181	-0.79	0.439
13 - 18	0.2038	0.0205	0.2171	0.0101	0.0202	-0.90	0.379
19 - 24	0.0929	0.0161	0.0995	0.0016	0.0158	-0.57	0.577
> 24	0.0601	0.0154	0.0643	0.0094	0.0152	-0.37	0.713
Calm	0.0099	0.0118	0.0043	0.0003	0.0116	0.65	0.523

Student's t-test: Wind Direction

Wind Direction	25YR Mean	25YR Stdev	2YR Mean	2YR Stdev	Stdev-Pooled	T-Statistic	P-Value
N	0.0643	0.0187	0.0681	0.0086	0.0184	-0.28	0.781
NNE	0.0292	0.0114	0.0256	0.0056	0.0113	0.43	0.670
NE	0.0169	0.0047	0.0159	0.0034	0.0046	0.29	0.777
ENE	0.0239	0.0097	0.0230	0.0032	0.0095	0.13	0.899
E	0.0484	0.0189	0.0442	0.0034	0.0186	0.31	0.758
ESE	0.0620	0.0117	0.0644	0.0029	0.0115	-0.28	0.782
SE	0.0507	0.0120	0.0515	0.0071	0.0118	-0.10	0.923
SSE	0.0399	0.0116	0.0431	0.0036	0.0114	-0.38	0.705
S	0.0314	0.0108	0.0345	0.0019	0.0106	-0.39	0.701
SSW	0.0299	0.0092	0.0267	0.0031	0.0091	0.48	0.637
SW	0.0677	0.0313	0.0429	0.0177	0.0309	1.09	0.286
WSW	0.1364	0.0235	0.1475	0.0301	0.0238	-0.64	0.530
W	0.1392	0.0246	0.1632	0.0078	0.0242	-1.35	0.190
WNW	0.0823	0.0115	0.0758	0.0099	0.0114	0.77	0.446
NW	0.0836	0.0164	0.0773	0.01	0.0162	0.53	0.604
NNW	0.0844	0.0116	0.0919	0.0042	0.0114	-0.90	0.378
Calm	0.0099	0.0118	0.0043	0.0003	0.0116	0.65	0.523

Discriminating Power of Student's t-test

Wind Speeds at two sites

Antelope 25YR Comparison to Gillette 2YR							
Speed (mph)	ACC 25YR Mean	ACC 25YR Stdev	Gil 2YR Mean	Gil 2YR Stdev	Stdev-Pooled	T-Statistic	P-Value
0 - 3	0.1210	0.0173	0.0551	0.0015	0.0170	5.29	0.000
4 - 7	0.2418	0.0331	0.1842	0.0039	0.0325	2.41	0.023
8 - 12	0.2706	0.0183	0.2590	0.0004	0.0179	0.88	0.387
13 - 18	0.2038	0.0205	0.2559	0.0126	0.0203	-3.50	0.002
19 - 24	0.0929	0.0161	0.0816	0.0054	0.0159	0.97	0.340
> 24	0.0601	0.0154	0.0581	0.0047	0.0151	0.18	0.860
Calm	0.0099	0.0118	0.1061	0.0074	0.0117	-11.22	0.000

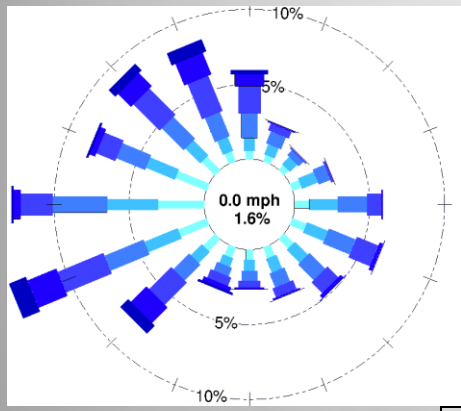
Discriminating Power of Student's t-test

Wind Directions at two sites

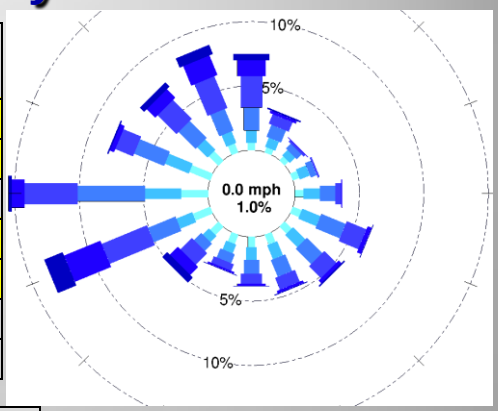
Antelope 25YR Comparison to Gillette 2YR							
Wind Direction	ACC 25YR Mean	ACC 25YR Stdev	Gil 2YR Mean	Gil 2YR Stdev	Stdev-Pooled	T-Statistic	P-Value
N	0.0643	0.0187	0.0651	0.00171	0.0183	-0.07	0.948
NNE	0.0292	0.0114	0.0347	0.00224	0.0112	-0.67	0.509
NE	0.0169	0.0047	0.0207	0.00216	0.0046	-1.13	0.270
ENE	0.0239	0.0097	0.0174	0.00385	0.0095	0.92	0.365
E	0.0484	0.0189	0.0203	0.00322	0.0186	2.06	0.050
ESE	0.0620	0.0117	0.0143	0.00103	0.0115	5.65	0.000
SE	0.0507	0.0120	0.0273	0.00046	0.0117	2.72	0.012
SSE	0.0399	0.0116	0.0671	0.00591	0.0114	-3.24	0.003
S	0.0314	0.0108	0.1152	0.01599	0.0111	-10.29	0.000
SSW	0.0299	0.0092	0.0493	0.00954	0.0092	-2.85	0.009
SW	0.0677	0.0313	0.0755	0.02027	0.0309	-0.35	0.733
WSW	0.1364	0.0235	0.0464	0.00286	0.0230	5.32	0.000
W	0.1392	0.0246	0.0779	0.00627	0.0242	3.46	0.002
WNW	0.0823	0.0115	0.0567	0.00454	0.0113	3.09	0.005
NW	0.0836	0.0164	0.1029	0.01573	0.0164	-1.60	0.121
NNW	0.0844	0.0116	0.1032	0.00811	0.0115	-2.22	0.036
Calm	0.0099	0.0118	0.1061	0.00741	0.0117	-11.22	0.000

Example of Student's-t False Positives:

Antelope Mine first 14 years vs. next 13 years



Speed (mph)	14YR Mean	14YR Stdev	13YR Mean	13YR Stdev	Stdev-Pooled	T-Statistic	P-Value
0 - 3	0.1283	0.0149	0.1108	0.01483	0.0149	3.04	0.005
4 - 7	0.2556	0.0345	0.2248	0.02021	0.0286	2.80	0.010
8 - 12	0.2652	0.0222	0.2780	0.00864	0.0171	-1.94	0.064
13 - 18	0.1923	0.0169	0.2182	0.01387	0.0155	-4.34	0.000
19 - 24	0.0867	0.0135	0.1006	0.01492	0.0142	-2.53	0.018
> 24	0.0602	0.0147	0.0607	0.01588	0.0153	-0.08	0.936
Calm	0.0117	0.0138	0.0070	0.00807	0.0114	1.08	0.291



Wind Speed

χ^2 phi-value = 0.12

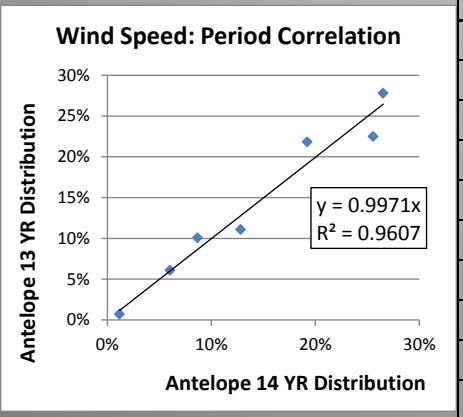
Regression R^2 = 0.96

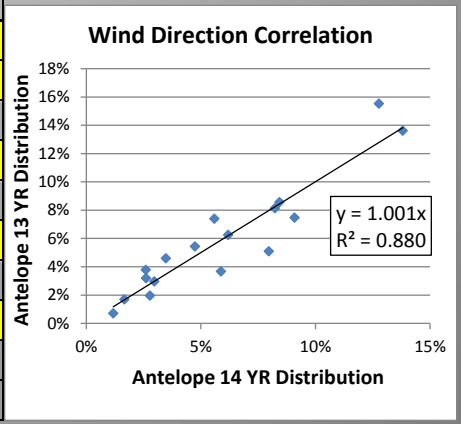
Wind Direction	14YR Mean	14YR Stdev	13YR Mean	13YR Stdev	Stdev-Pooled	T-Statistic	P-Value
N	0.0559	0.0198	0.0738	0.01007	0.0159	-2.93	0.007
NNE	0.0261	0.0055	0.0320	0.01462	0.0109	-1.41	0.171
NE	0.0166	0.0031	0.0169	0.00588	0.0046	-0.16	0.873
ENE	0.0278	0.0110	0.0195	0.00441	0.0085	2.51	0.019
E	0.0588	0.0176	0.0366	0.0104	0.0146	3.93	0.001
ESE	0.0620	0.0116	0.0625	0.01137	0.0115	-0.12	0.907
SE	0.0474	0.0137	0.0543	0.00781	0.0112	-1.58	0.126
SSE	0.0348	0.0101	0.0460	0.00955	0.0098	-2.95	0.007
S	0.0260	0.0086	0.0377	0.00883	0.0087	-3.49	0.002
SSW	0.0297	0.0121	0.0296	0.00382	0.0091	0.03	0.979
SW	0.0796	0.0361	0.0510	0.01419	0.0278	2.67	0.013
WSW	0.1382	0.0141	0.1361	0.03129	0.0239	0.22	0.825
W	0.1278	0.0259	0.1553	0.01229	0.0206	-3.48	0.002
WNW	0.0823	0.0109	0.0813	0.01222	0.0115	0.23	0.822
NW	0.0909	0.0180	0.0747	0.00743	0.0140	3.02	0.006
NNW	0.0844	0.0138	0.0856	0.00851	0.0116	-0.28	0.782
Calm	0.0117	0.0138	0.0070	0.00807	0.0114	1.08	0.291

Wind Direction

χ^2 phi-value = 0.22

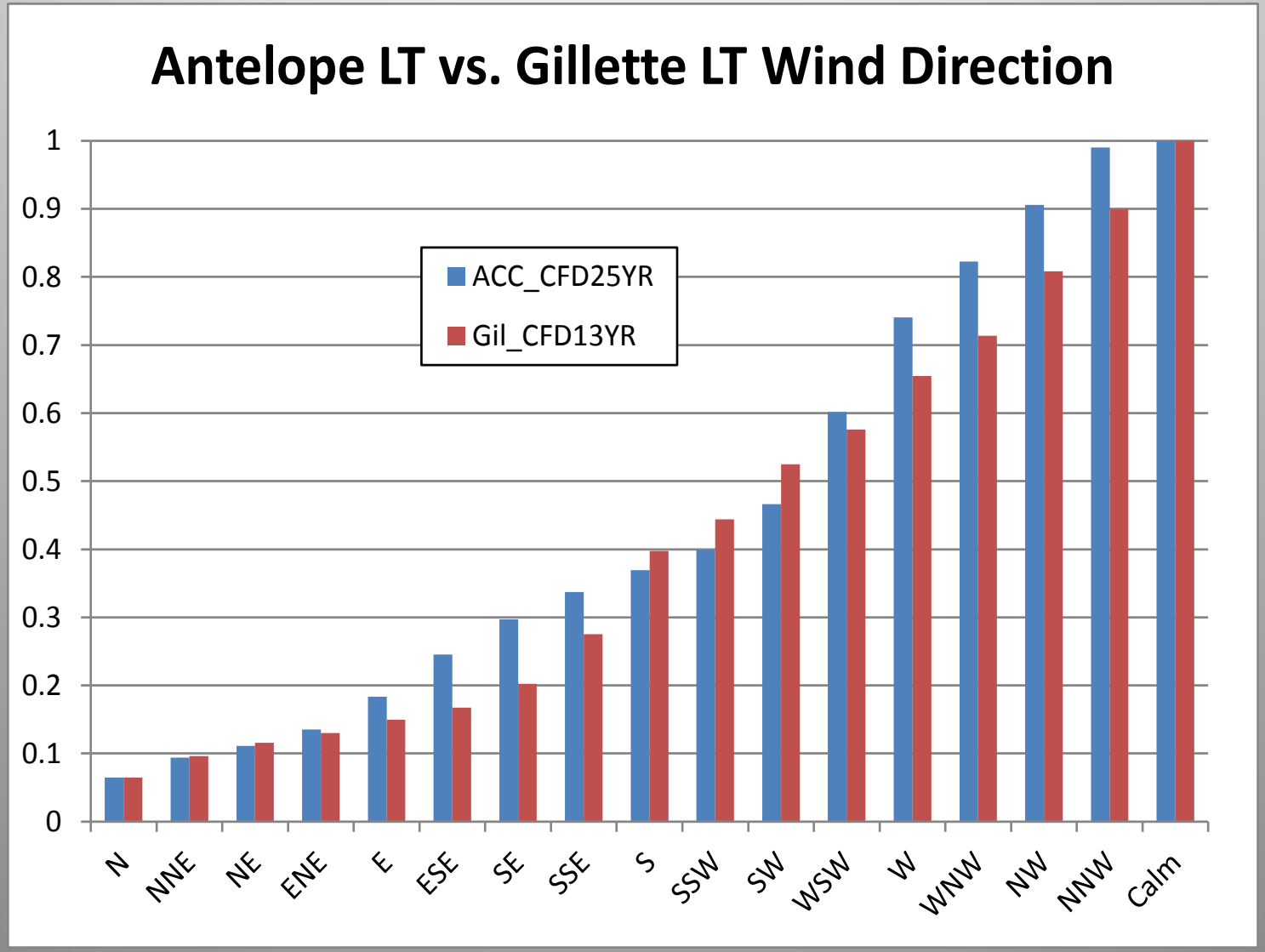
Regression R^2 = 0.88





Kolmogorov-Smirnov: Wind Direction

Maximum cumulative difference produces false negatives



Characteristics of Hypothesis Testing

- Excels at demonstrating differences, not similarities
- Provides a yes/no decision that depends on the chosen confidence level
- Outcome is sensitive to sample size and data categorization (not valid for JFD's)
- Kolmogorov-Smirnov test does not differentiate between similar and dissimilar wind patterns
- Chi-Square test produces false positives due to large sample size (can be adjusted, however)
- Student's t-test is effective, but must be applied individually to each data category, and also risks false positives

Conclusion: Comprehensive Analysis (Mutually Reinforcing Tests)

15-Yr vs. 4-Yr Frequency Distributions	Statistical Method							Overall Conclusion
	χ^2 at 8,760 hrs.	Ø-Coeff.	Adjusted χ^2 Result	t-test min. p-value	t-test Result	Linear Regress. R^2	Regress-ion Result	
Wind Speed	4.8	0.11	Similarity	0.287	No statistical difference	0.999	Strongly Similar	No statistical difference
Wind Direction	113	0.02	Similarity	0.172	No statistical difference	0.962	Strongly Similar	No statistical difference
Joint Wind Speed and Wind Direction	N/A	N/A	N/A	N/A	N/A	0.951	Strongly Similar	No statistical difference
Atmospheric Stability Class	84.6	0.10	Similarity	N/A	N/A	0.999	Strongly Similar	No statistical difference

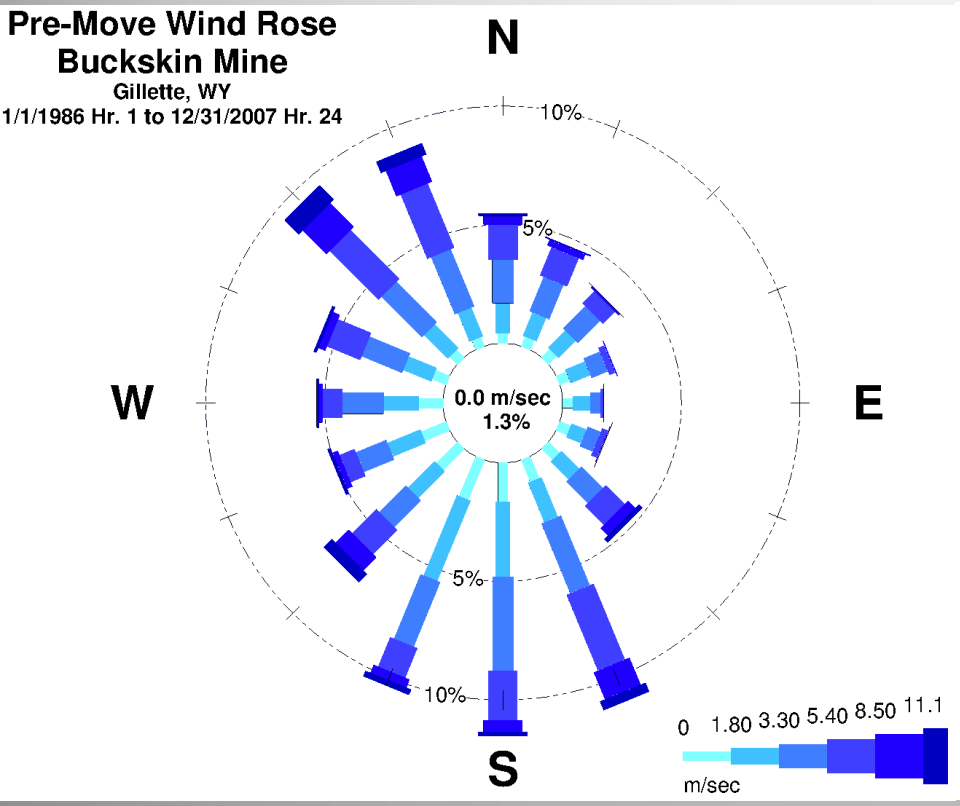
Qualification #1: Monitoring Uncertainty May Overwhelm Temporal Uncertainty

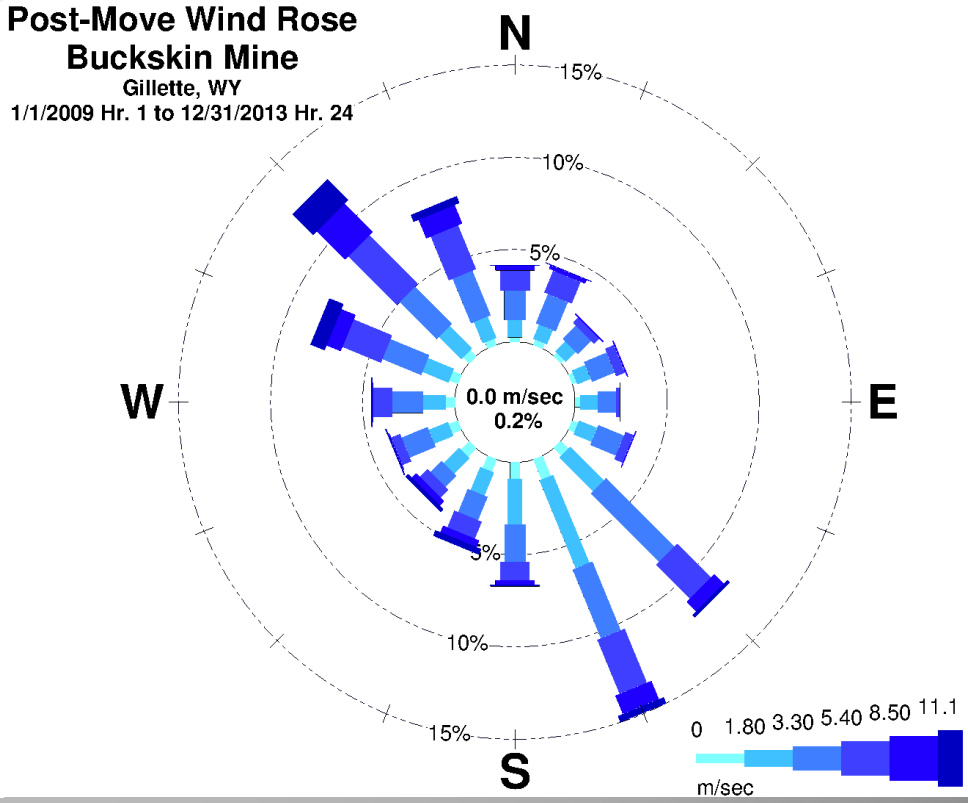
- National Weather Service (NWS) data resolution: 1 mph and 10°, with 3 mph starting threshold (NWS meets NRC guidance)
- EPA Data Resolution : 0.2 mph and 1°, with 1 mph starting threshold (IML meets EPA guidance)
- NWS rounding of wind directions introduces bias toward four cardinal directions, due to misalignment between 10° rounding intervals and 22.5° direction intervals used by MILDOS
- NWS high starting threshold introduces bias toward calm winds and misses corresponding wind directions

Qualification #2: Spatial Uncertainty Overwhelms Temporal Uncertainty

- Average wind conditions can vary more between two neighboring sites than they do between short and long term periods at a given site

Dominance of Spatial over Temporal Variation:
Buckskin Mine Met Tower Moved 2 Miles in 2008





- Chi-Square test shows wind data are significantly different, even adjusted for sample size
- Student's-t test shows wind data are significantly different for certain wind speed and direction categories

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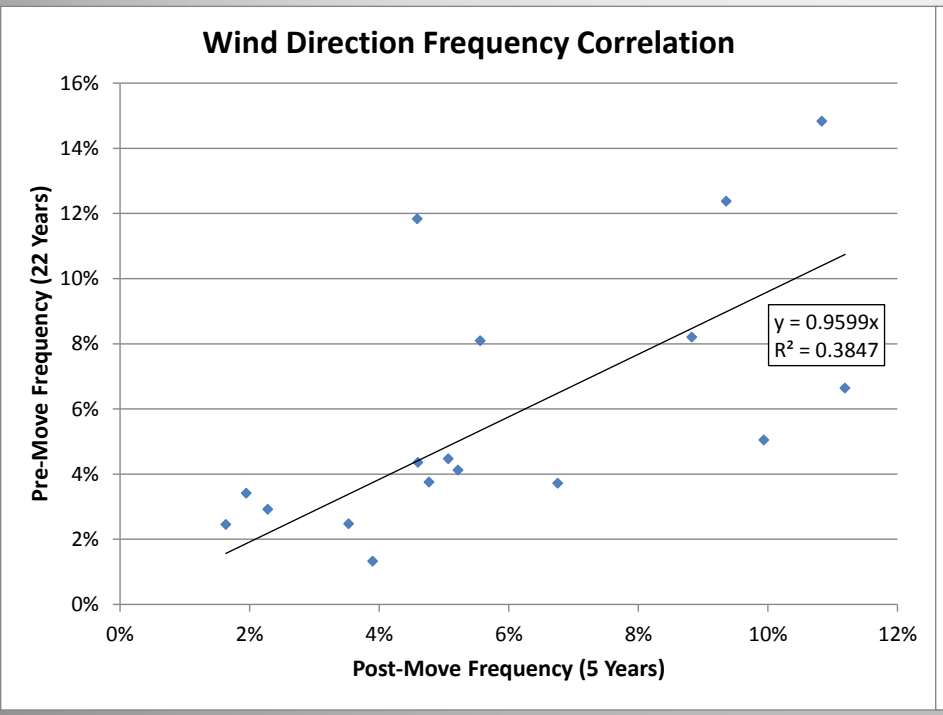
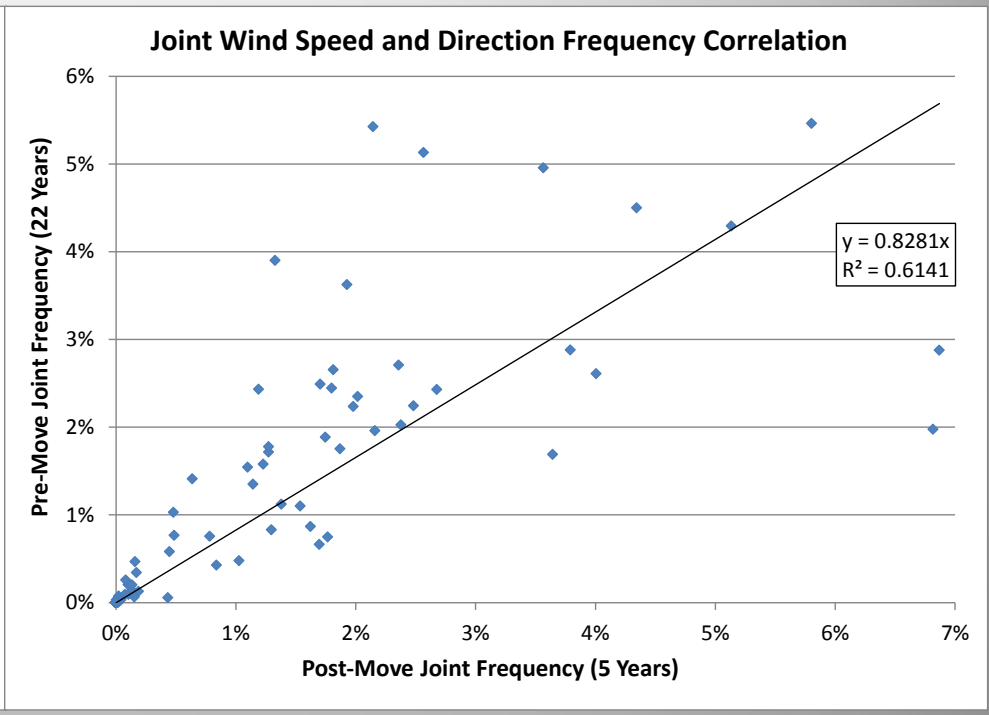




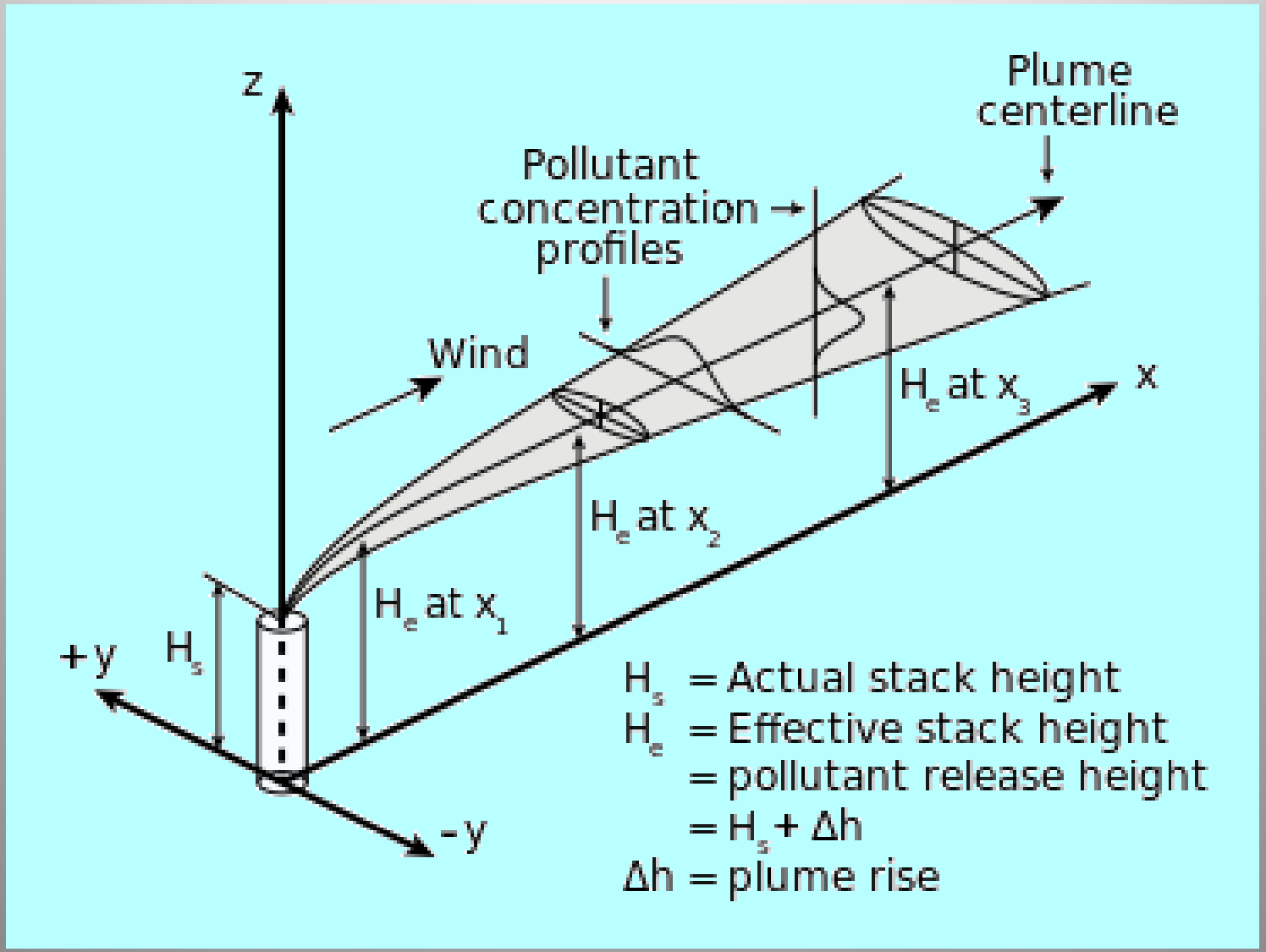
- Linear regression shows wind direction frequencies not linearly correlated (R^2 = 0.385)
- Linear regression shows joint wind speed and direction frequencies only weakly correlated (R^2 = 0.614)

Why Does This Matter?

- Steady-State models project each joint wind speed, wind direction and stability class over the entire modeling domain for the associated time interval
- Accordingly for each modeled set of conditions, MILDOS assumes spatially uniform winds between source and receptors
- Sensitive receptors are generally 10 km or more from the source and from the on-site met tower

MILDOS Model

Steady-state, Gaussian plume dispersion



MILDOS Ignores Plume Meander

Non-steady-state, fluctuating dispersion