Field Comparison of Maximum Cup, Climatronics F460 and Met One 010C Anemometers

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Compare Concurrent Wind Speeds

- New, calibrated sensors
  - Wind Tunnels, Otech (rig on automobile)
- Project site in Altamont Pass
- Common crossarm, common logger (CS 21x)
- Collect 10-minute averages & std. dev.
- Maximum Cup with and without boot
  - Measure three ways - calibrated, consensus and EWC transfer functions
- Climatronics used as reference

Data Analysis / Comparisons

- Gross averages - wind speed ratios
- Speed ratios as function of wind speed
- Theoretical energy calculation - 750 kW turbine
- Turbulence Intensity
- Boot on / boot off
- Implications of results

Maximum Cup Linear Transfer Functions

	Slope		Offset	
Source	m/s/Hz	(mph/Hz)	m/s	(mph)
Calibration	0.7595	(1.6990)	0.516	(1.154)
Consensus	0.7649	(1.7110)	0.349	(0.780)
EWC	0.7577	(1.6949)	0.000	(0.000)

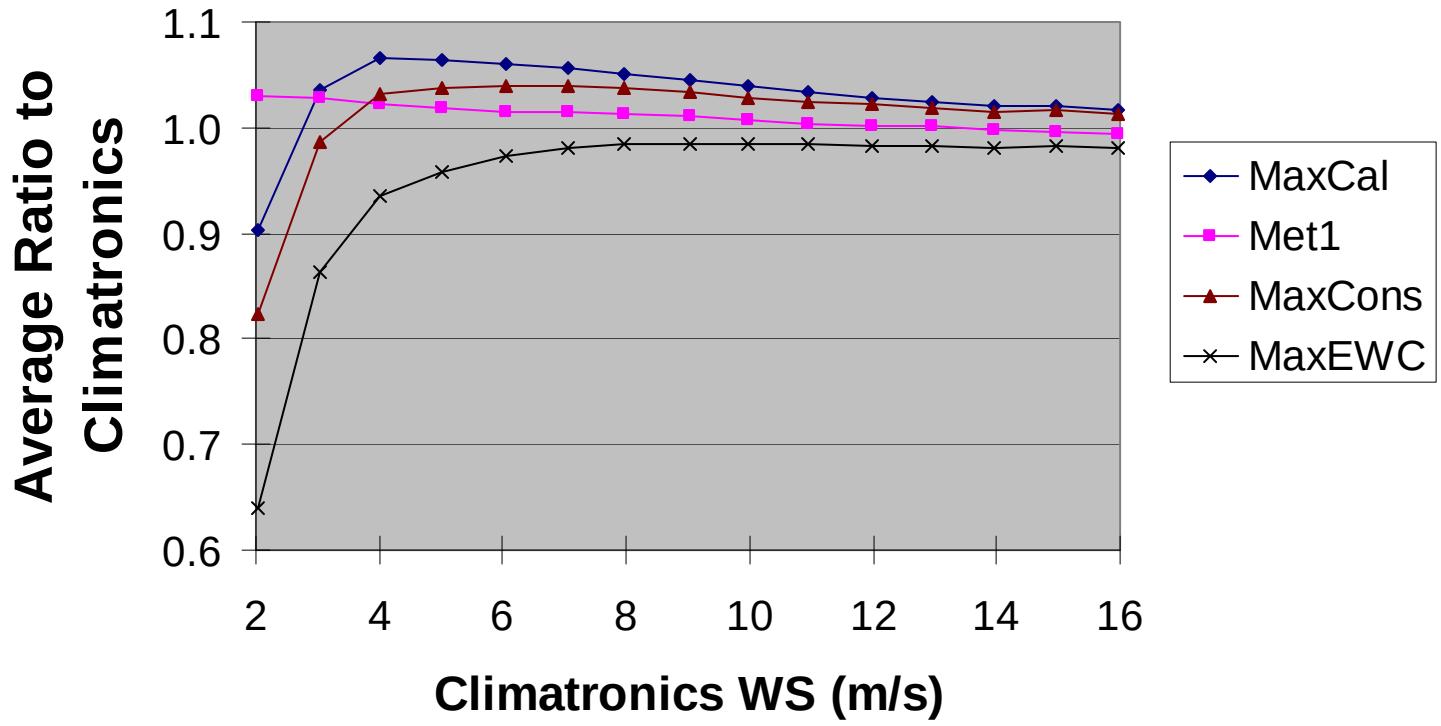
Average Wind Speeds and Ratios to Climatronics - w/ boot - 1393 records

	Clim	Met1	MaxCal	MaxCons	MaxEWC
m/s	9.00	9.07	9.36	9.26	8.83
mph	(20.13)	(20.28)	(20.94)	(20.71)	(19.74)
Ratio to Clim	1.000	1.007	1.040	1.029	0.981

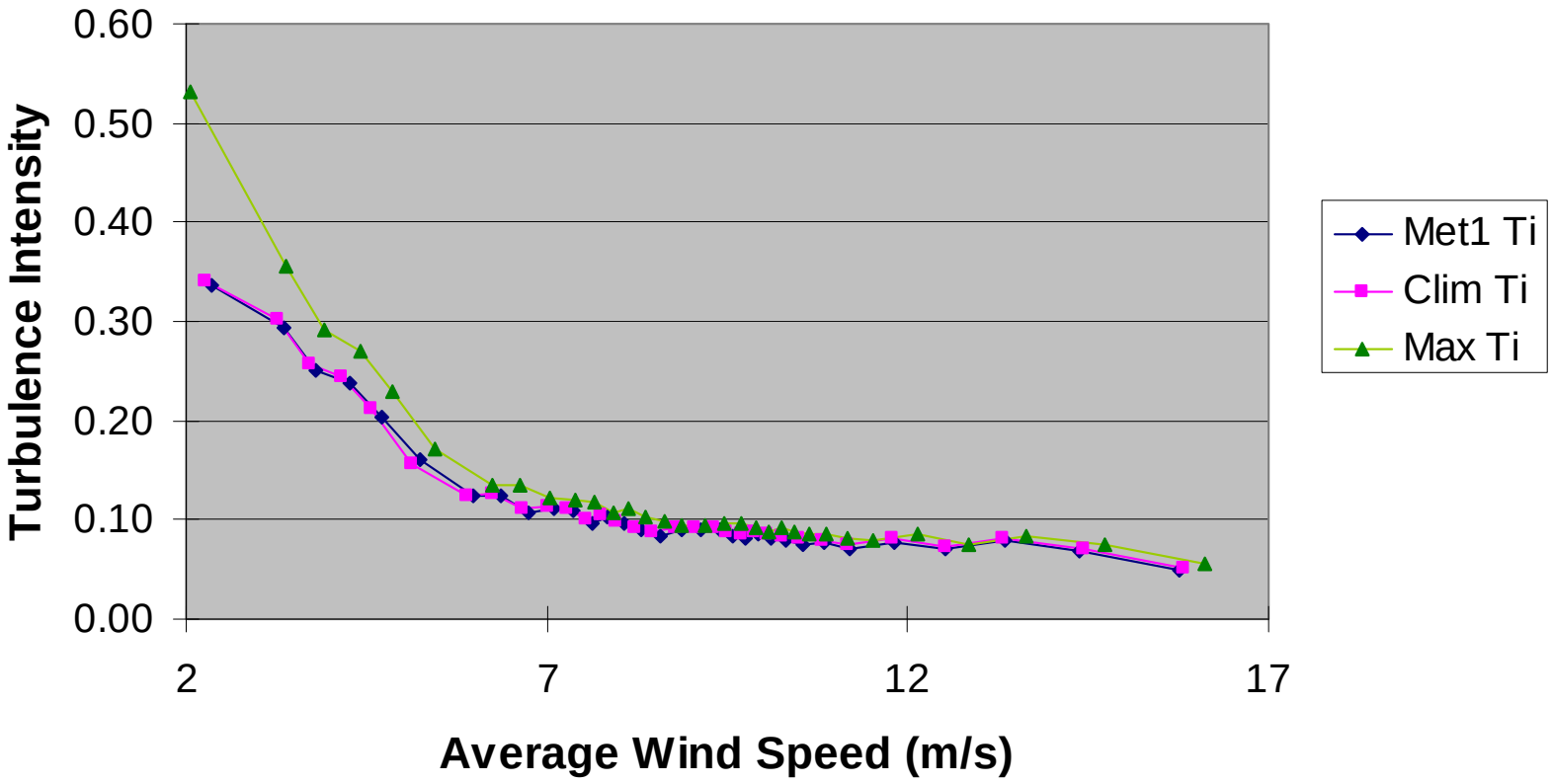
Theoretical Energy Calculation and Ratios to Climatronics 750 kW Power Curve - with boot

	Clim	Met1	MaxCal	MaxCons	MaxEWC
kWh	74,131	75,368	80,468	78,717	71,396
Ratio	1.000	1.017	1.085	1.062	0.963

Average Wind Speed Ratios to Climatronics Maximum Cup with Boot



Turbulence Intensity vs Average Wind Speed
Maximum Cup with boot



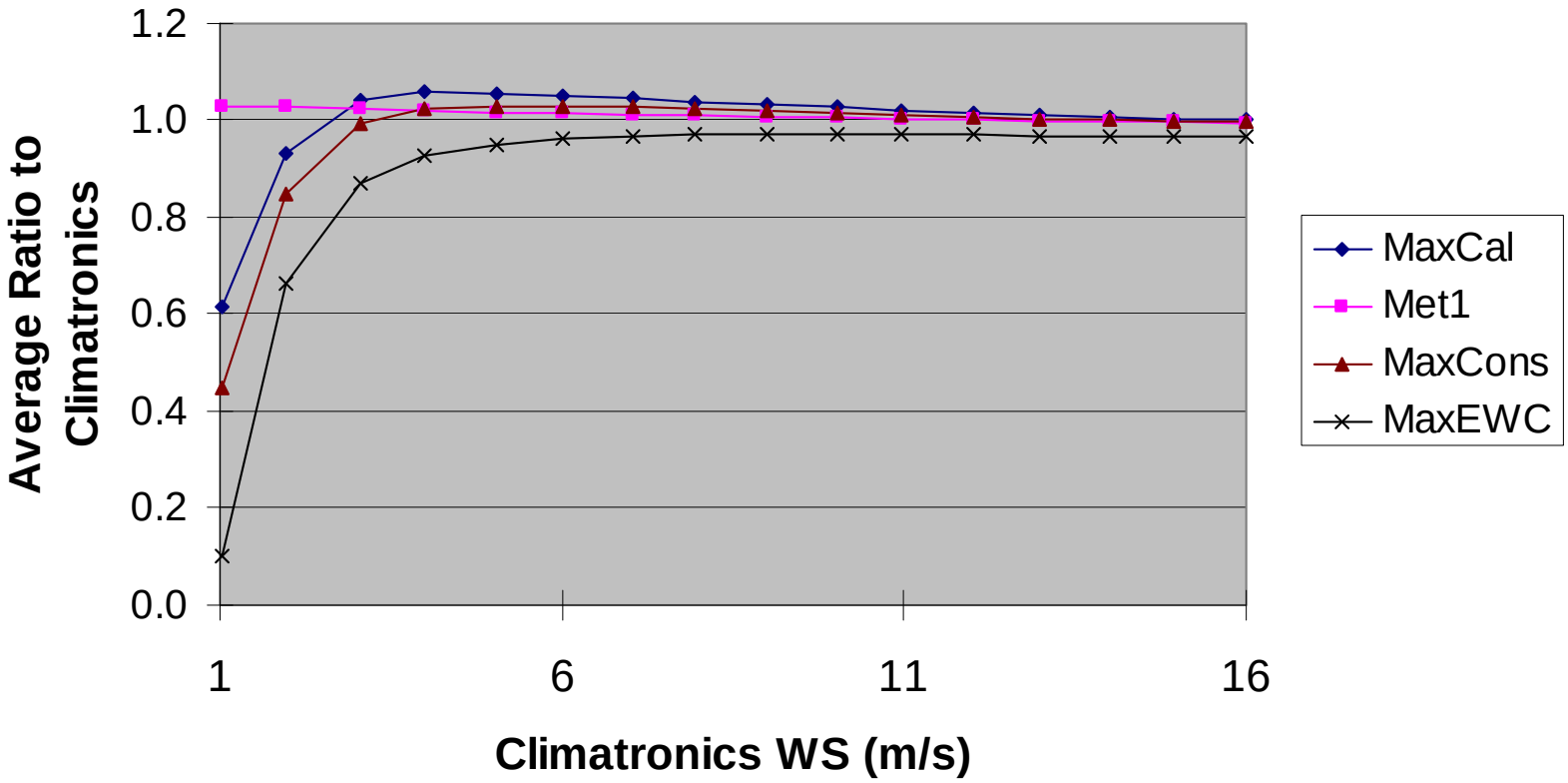
Average Wind Speeds and Ratios to Climatronics - no boot - 1153 records

	Clim	Met1	MaxCal	MaxCons	MaxEWC
m/s	9.59	9.63	9.79	9.69	9.25
mph	(21.45)	(21.53)	(21.90)	(21.67)	(20.69)
Ratio to Clim	1.000	1.004	1.021	1.010	0.965
Booted Ratio	1.000	1.007	1.040	1.029	0.981

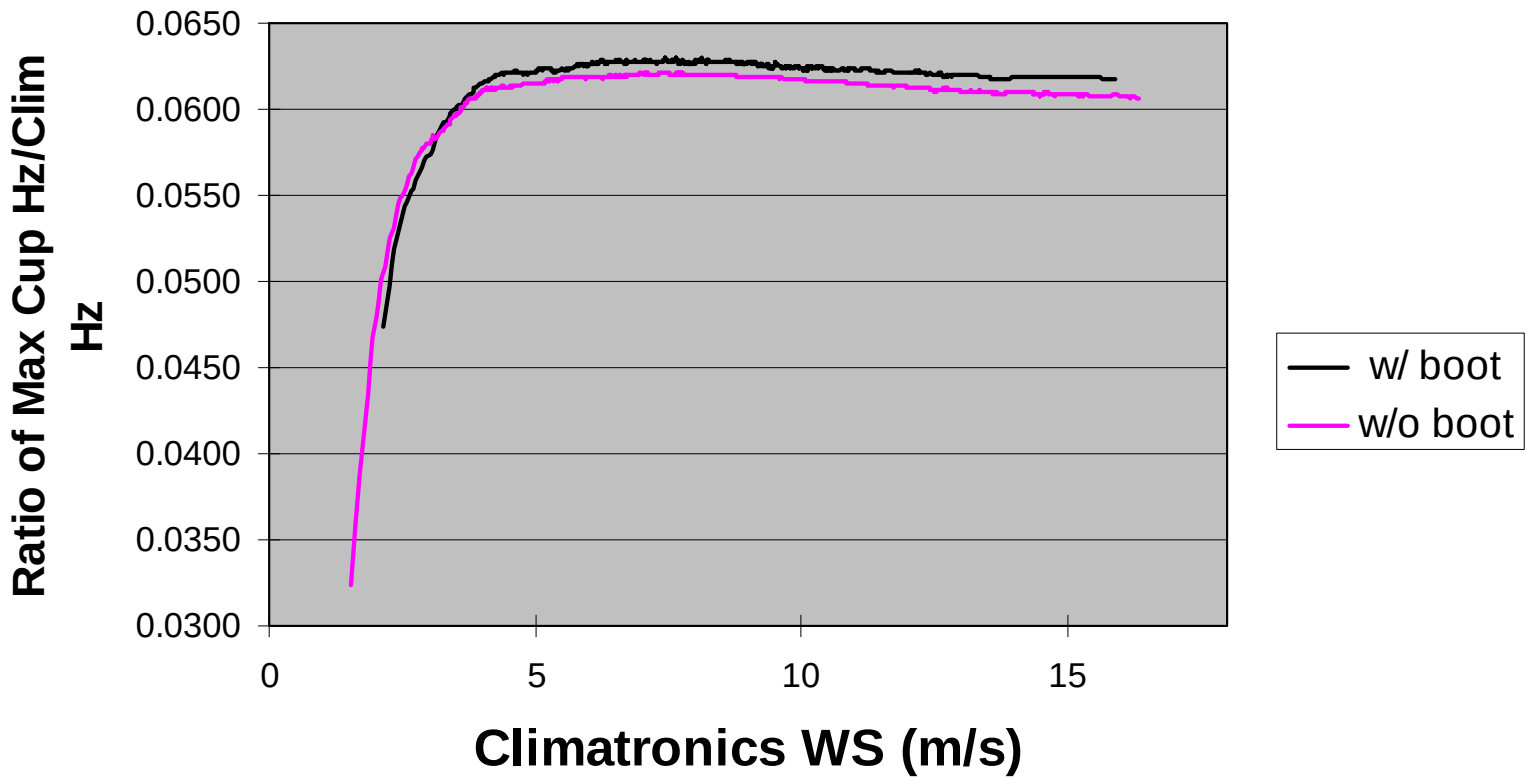
Theoretical Energy Calculation and Ratios to Climatronics 750 kW Power Curve - without boot

	Clim	Met1	MaxCal	MaxCons	MaxEWC
kWh	72,068	72,543	74,702	73,559	68,637
Ratio	1.000	1.007	1.037	1.021	0.952
Ratio w/ boot	1.000	1.017	1.085	1.062	0.963

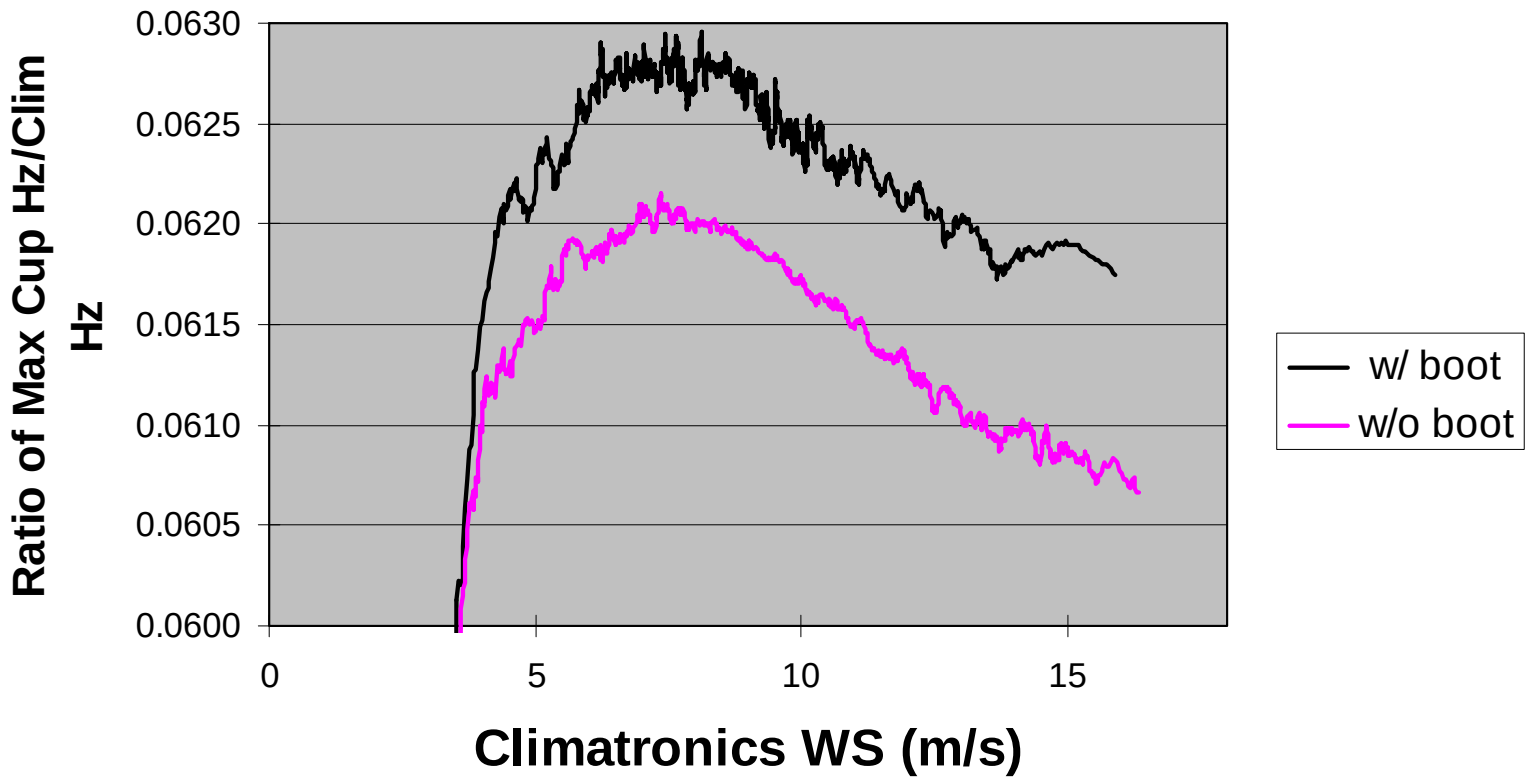
Average Wind Speed Ratios to Climatronics
Maximum Cup without Boot



Ratio of Max Cup Hz to Clim Hz vs Clim WS
Maximum Cup with and without boot



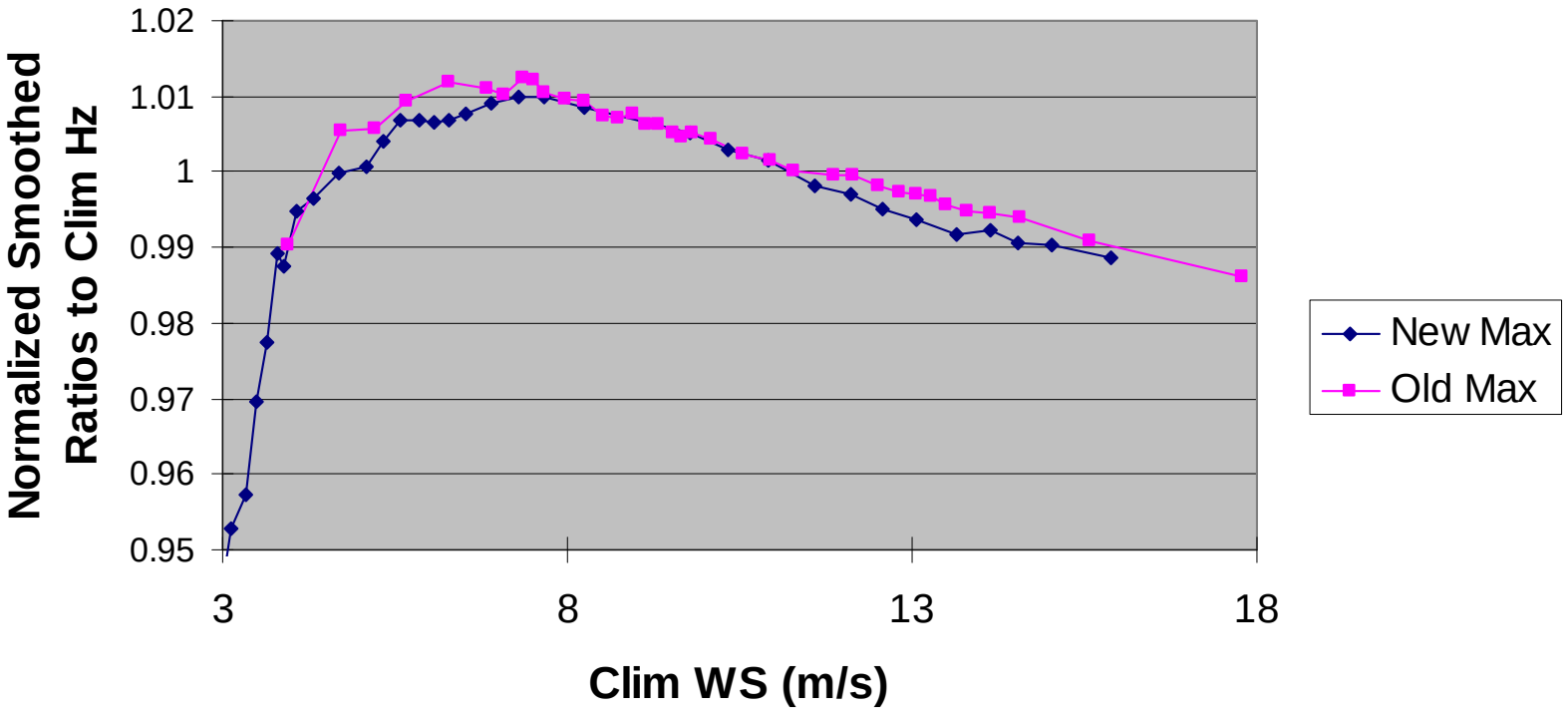
Ratio of Max Cup Hz to Clim Hz vs Clim WS
Maximum Cup with and without boot



Correction to Maximum Cup Wind Speeds to Simulate Climatronics

- Third-order polynomial for Hz $\leq$ 10.3
- Linear transfer function for Hz $\geq$ 10.3
- Coefficients, slopes and offsets developed for booted and non-booted sensors.
- Post-processing or used during data logging.
- Tested with used Maximum Cup.
- Field test error ~1%.

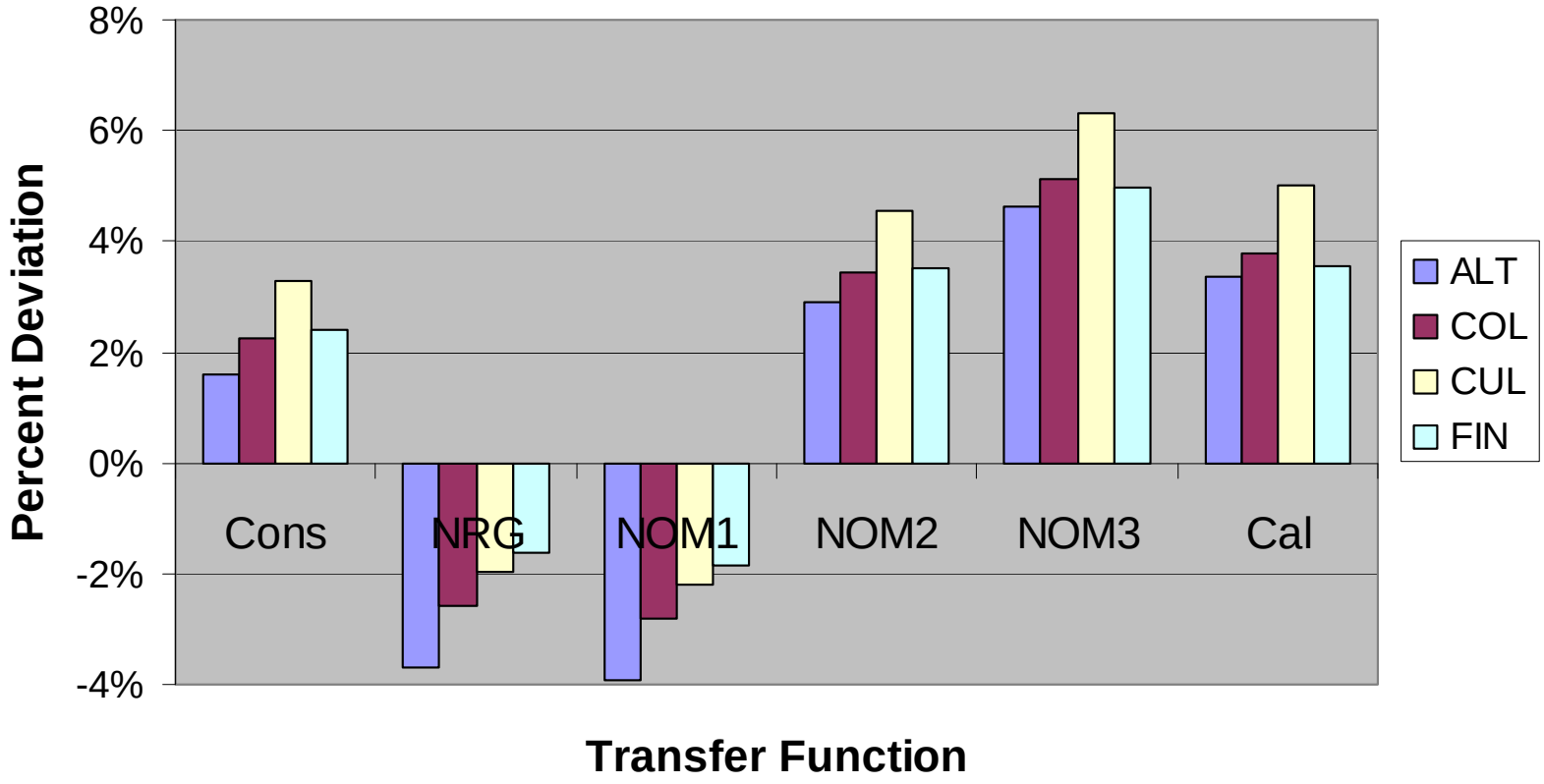
Normalized Smoothed Average Ratios of New Max Hz and Old Max Hz / Clim Hz vs Clim WS



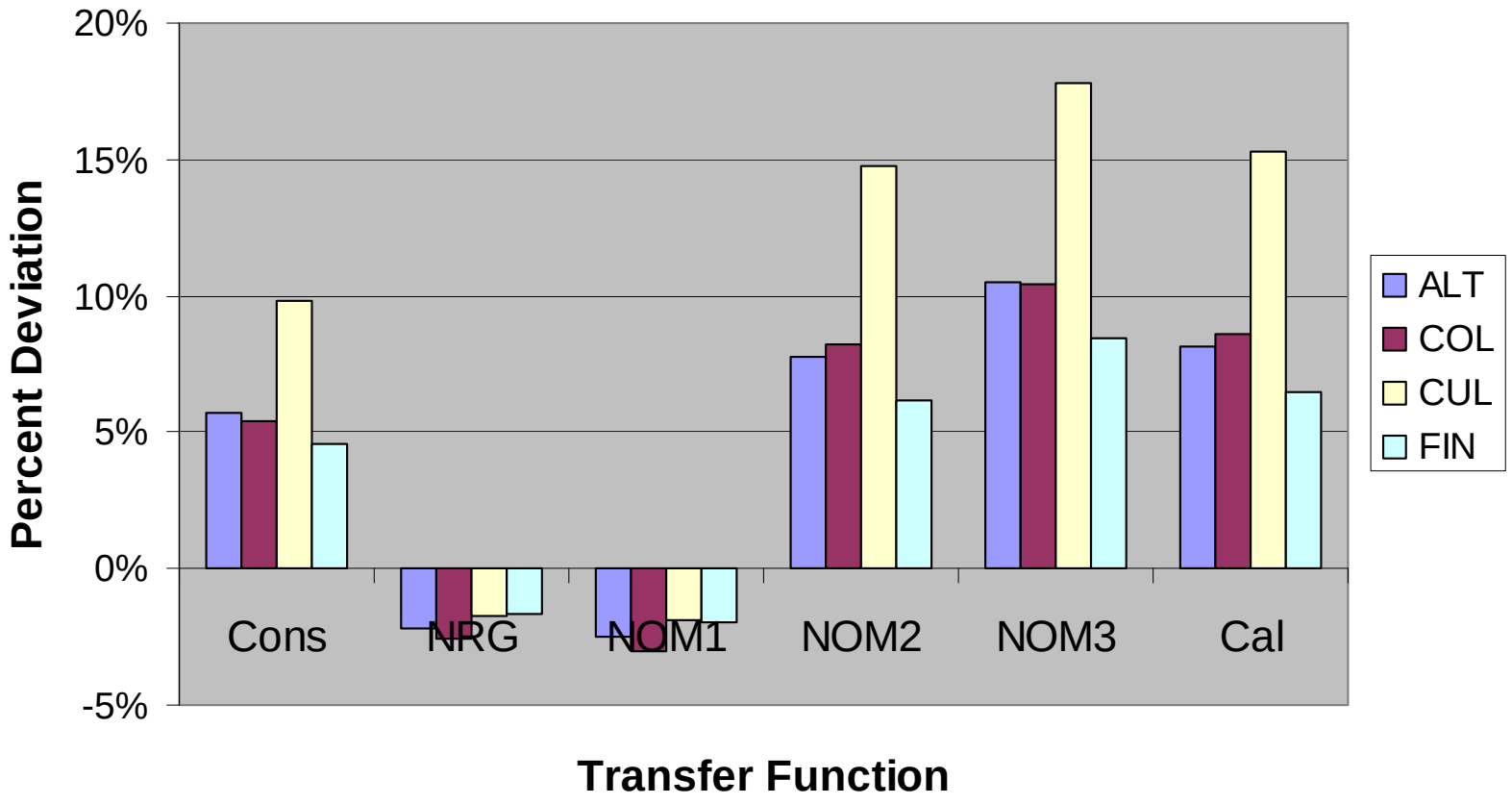
Default Slopes and Offsets in NRG and Second Wind Data Loggers

	Slope		Offset	
	m/s/Hz	mph/Hz	m/s	mph
NRG	0.7637	(1.708)	0.000	(0.000)
NOMAD 1	0.7617	(1.704)	0.000	(0.000)
NOMAD 2	0.7689	(1.720)	0.402	(0.900)
NOMAD 3	0.7734	(1.730)	0.483	(1.080)

Percent Deviation of Average WS from Simulated Climatronics



Percent Deviation of Annual Energy from Simulated Climatronics



Conclusions

- Free-atmosphere comparison revealed unexpected subtleties in anemometer performance, probably not observed in wind tunnel.
- Climatronics and Met One compared well.
- Maximum Cups showed non-linear performance degradation in wind speeds < ~8 m/s.
- Boot causes Maximum Cup to spin faster.
- Ti is the same for all sensors at WS > ~9 m/s

- Significant errors in wind speed and theoretical energy possible with Maximum Cups.

Recommendations

- Comparative testing of other ball bearing anemometers and Maximum Cups.
- Side-by-side comparison of different sensors to be used for different purposes or…
- Consistent use of the same type of anemometer ($$$).
- Consider correcting wind speed data from Maximum Cups.
- Carefully consider whether to use Maximum Cups for power curve testing.

Average Ratios to Climatronics
Maximum Cup with boot