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Improved Wind and Turbulence Measurements Using a Low-Cost 3-D Sonic Anemometer at a Low-Wind Site

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IMPROVED WIND AND TURBULENCE MEASUREMENTS USING A LOW-COST 3-D SONIC ANEMOMETER AT A LOW-WIND SITE

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Sonic Anemometer Use Increasing



- **Advantages**
 - Low/No Maintenance Requirements
 - Measurements at very low wind speeds
 - Improved technology \Rightarrow lower cost
- **Recent Conversions to 2-D Sonics**
 - NWS/FAA (ASOS)
 - Tennessee Valley Authority
- **Recent Conversions to 3-D Sonics**
 - South Coast Air Quality Management District (CA)
 - Army Research Laboratory

Regional Area (Toward South)



05-02-05

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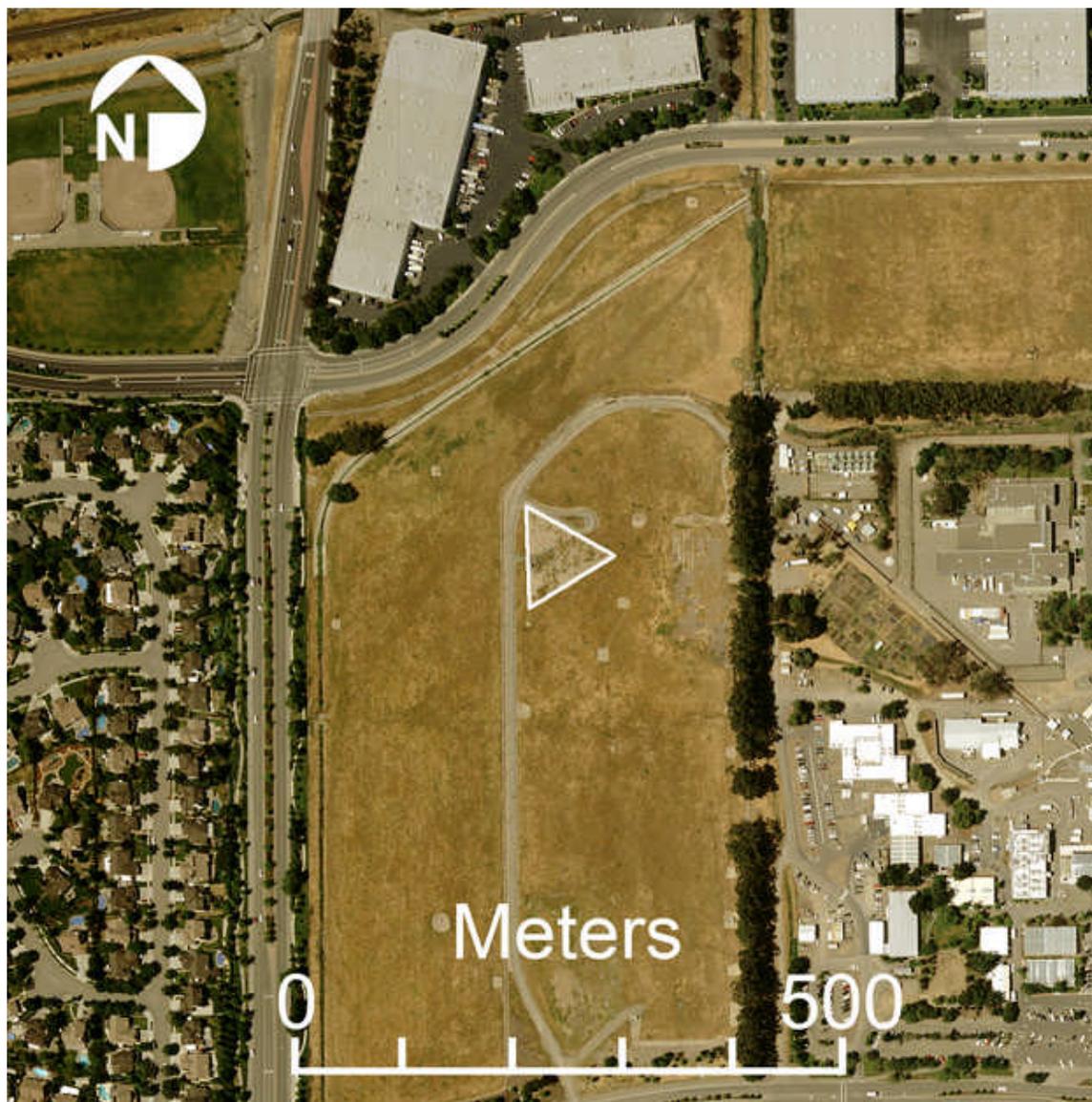
2,700 ASL

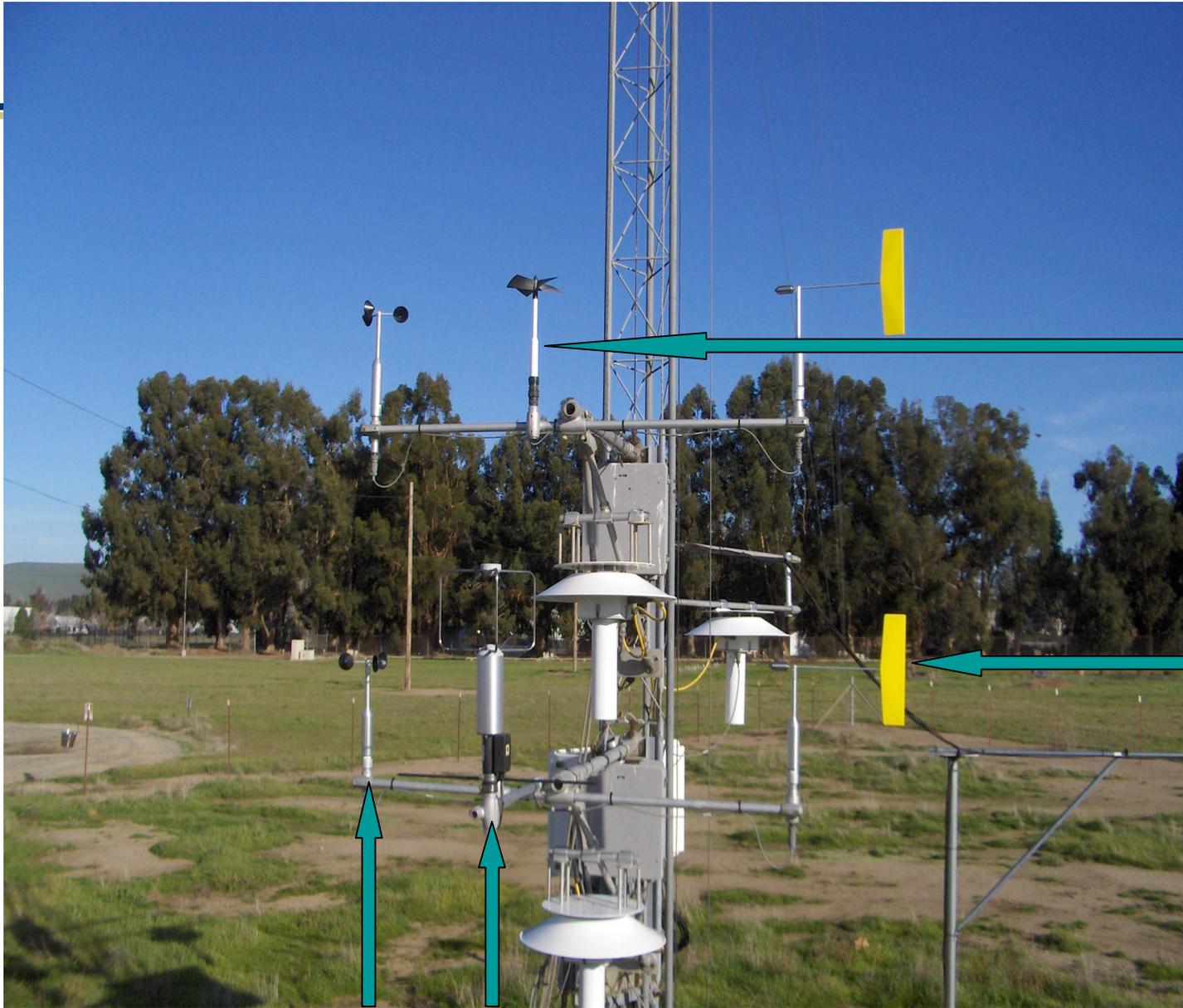
SITE 200

45-3



Local Area Around Tower





Vertical Prop

Vane

Cup Anem.

Sonic

Sensor Orientation

Sensor Characteristics



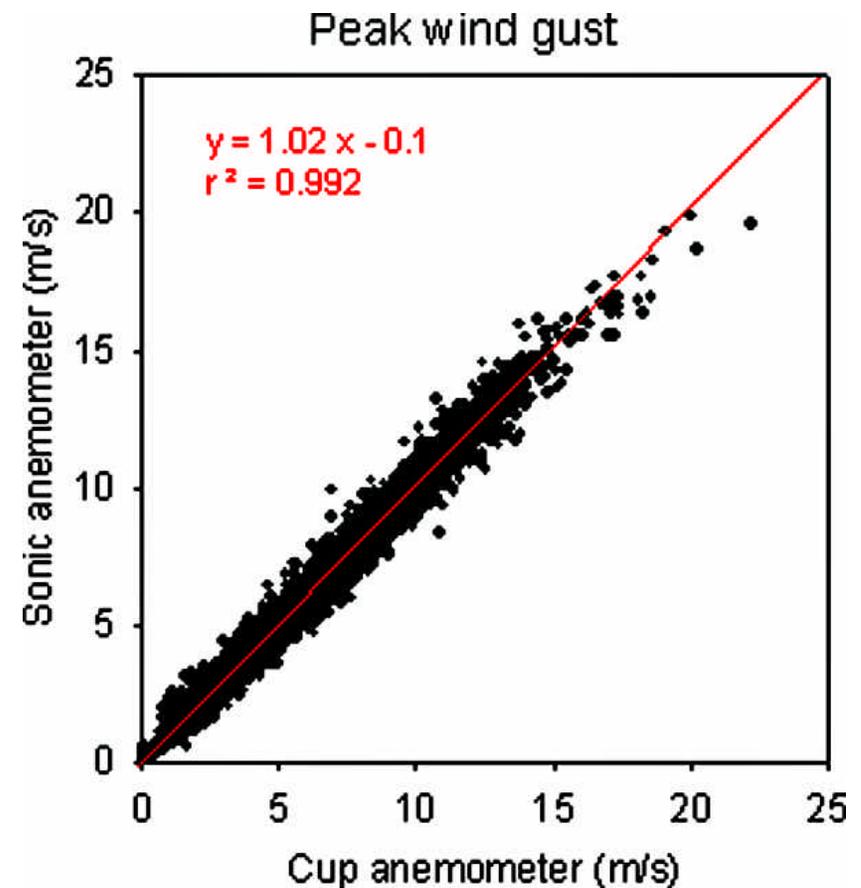
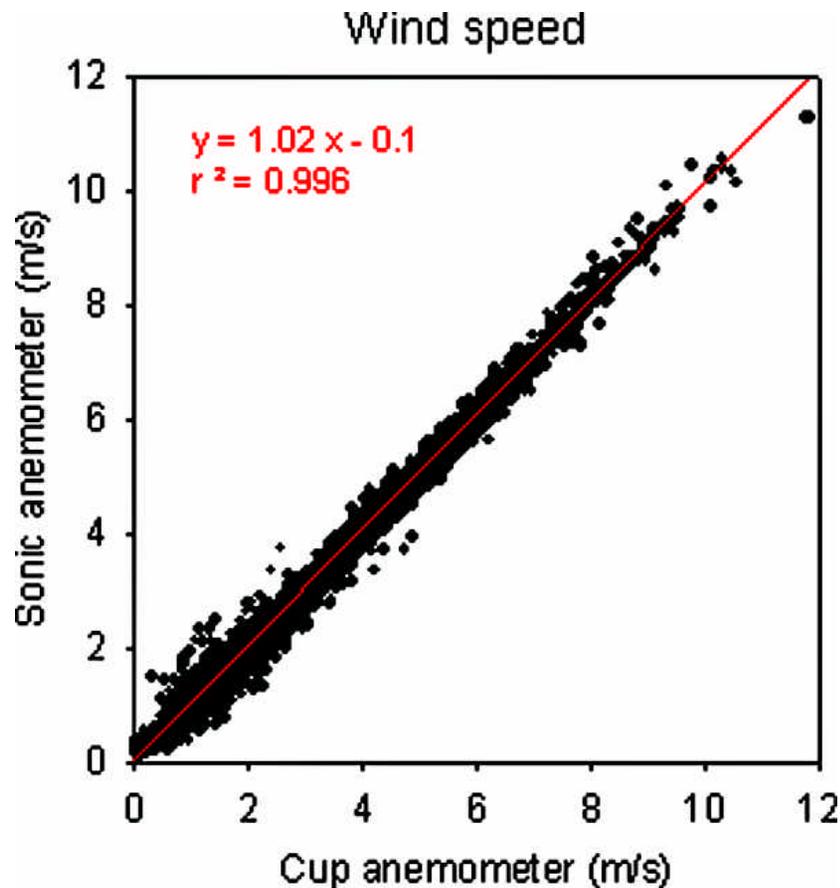
- **R.M. Young 81000 Sonic:**
 - 3 pairs of opposing ultrasonic transducers
 - 0.01-**0.2** m/s starting threshold
 - 160 Hz internal, **4-32** Hz external sampling rate
- **Met One Sensors:**
 - 010C wind vane: +/- 3°, D.C. < 0.9 m
 - 020C anem: +/-1%(<30 m/s), D.C.<1.5 m
 - starting thresholds = 0.22 m/s
- **R.M. Young 27106F propeller:**
 - +/-1%(+/-20 m/s), D.C. = 2.1 m
 - 1.25 factor for non-cosine response
 - starting threshold = 0.22 m/s

Data Analyses



- **Year of 15-min. data (2004) from sonic & mechanical sensors analyzed/compared:**
 - 15-min. avg. & peak (1-sec.) scalar wind speed (u)
 - standard deviation of along-wind fluctuations (σ_u)
 - wind direction (θ) and its standard deviation (σ_θ)
 - standard deviation of vertical wind (σ_w) and angle fluctuations (σ_ϕ) [note: $\sigma_\phi \cong \sigma_w/u$]
 - vertical momentum flux ($-u'w'$)
- **Suspicious data deleted**
- **All data measured at 1 Hz rate**

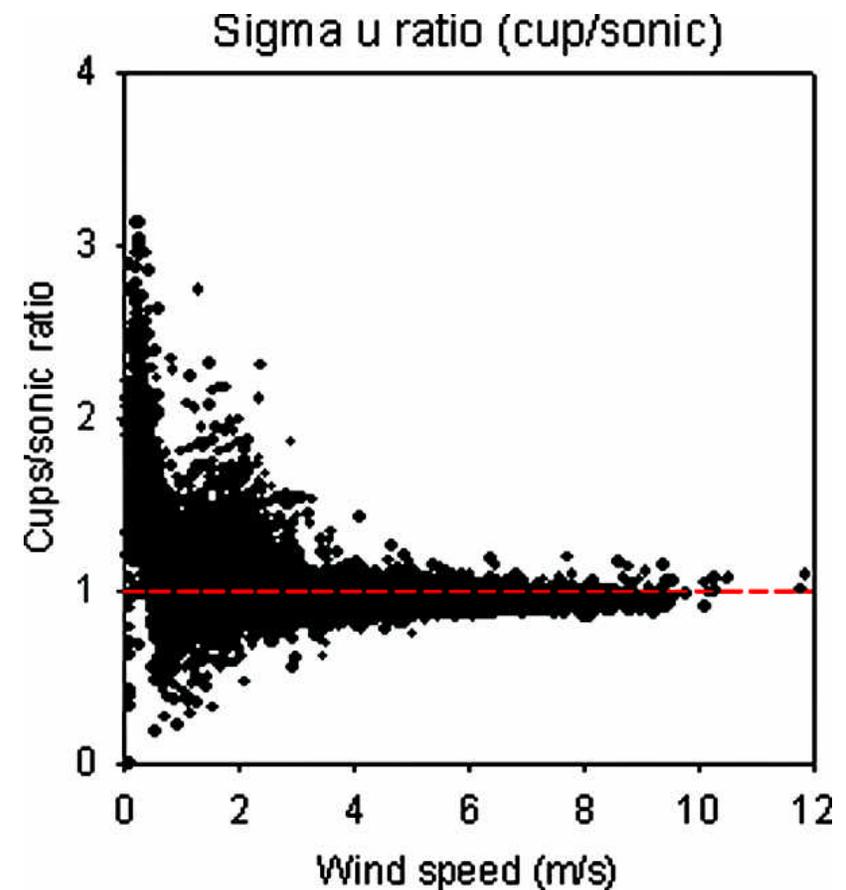
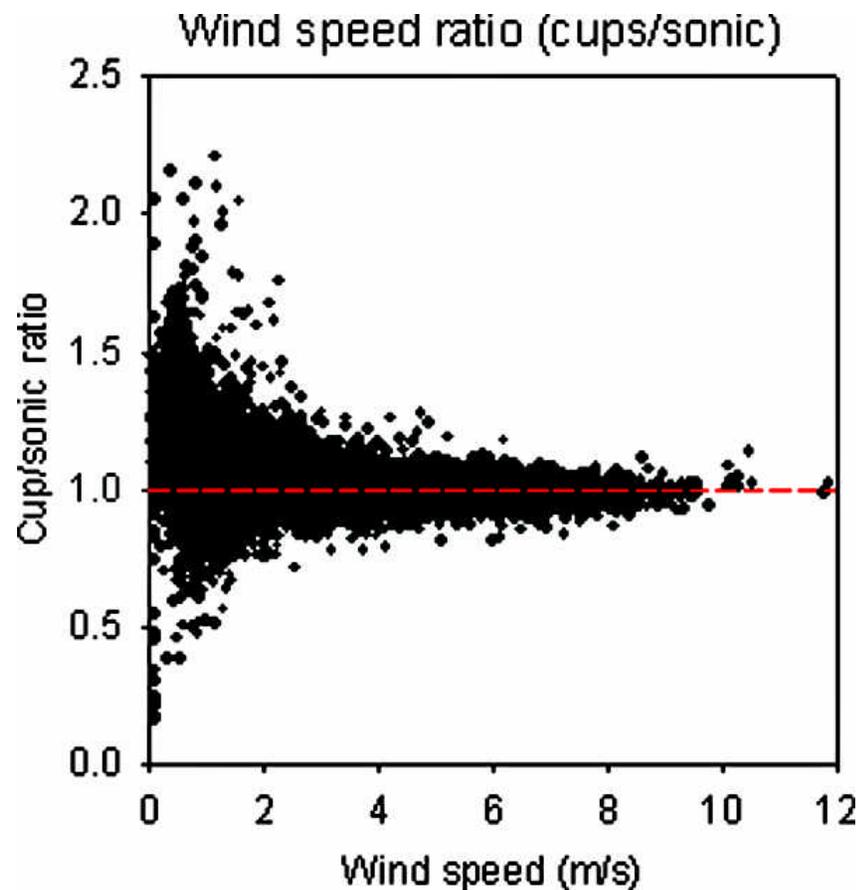
Wind Speed & Gust Correlations



Very good over-all correlation...



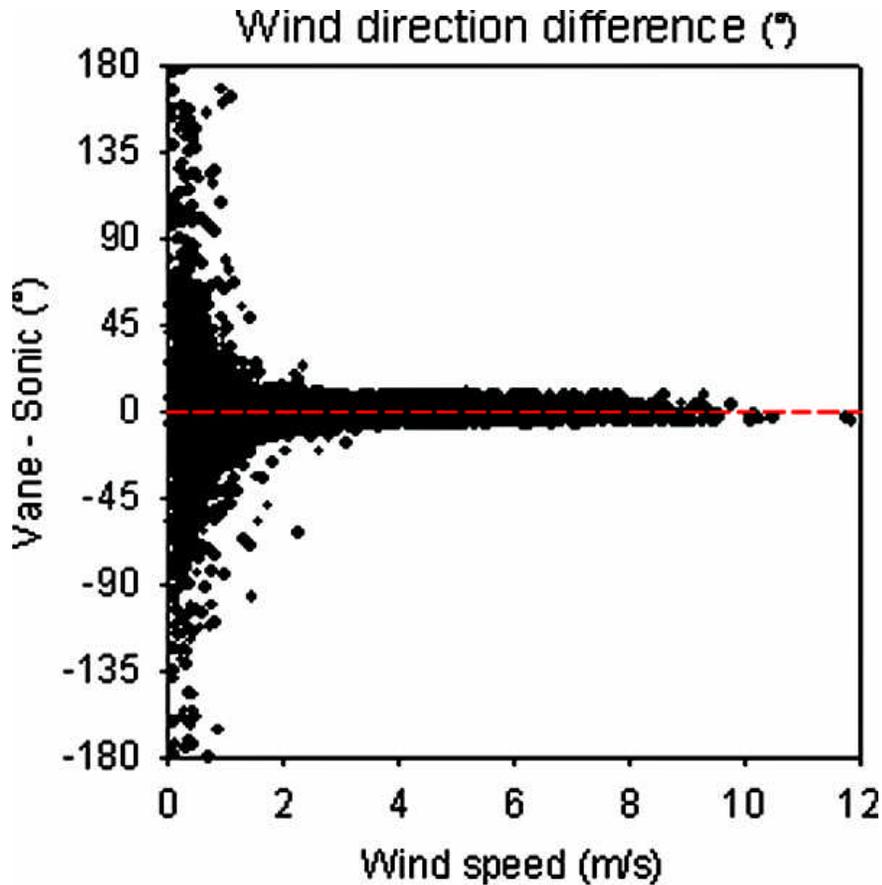
Wind Speed & σ_u Ratios



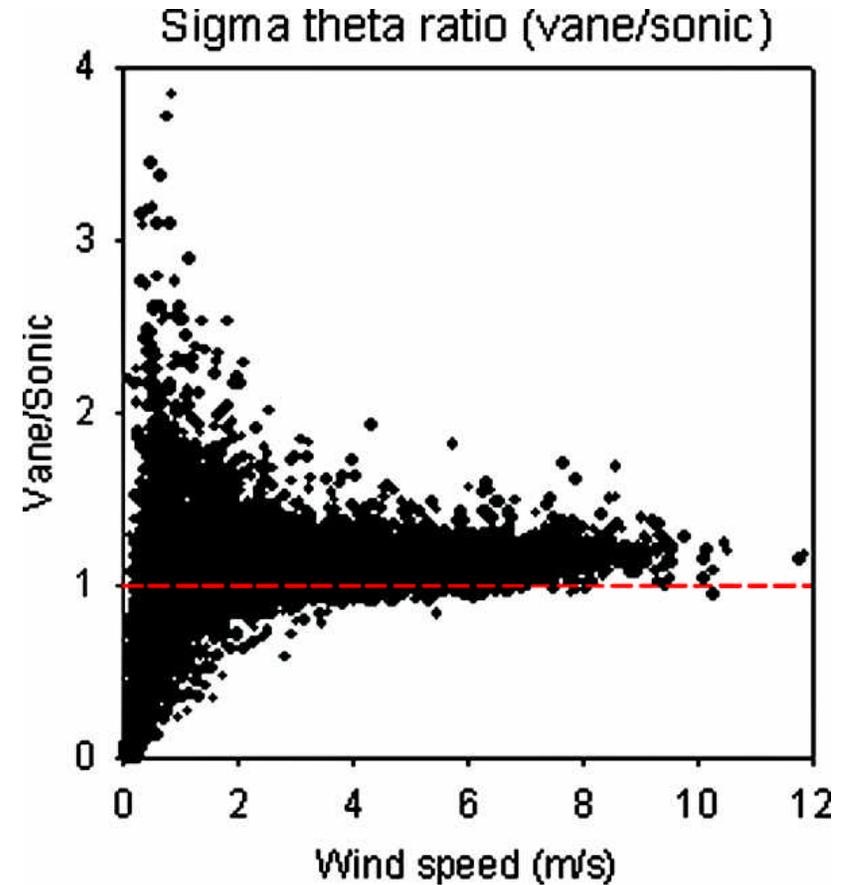
But large bias at low speeds



Wind Direction & σ_θ Comparison



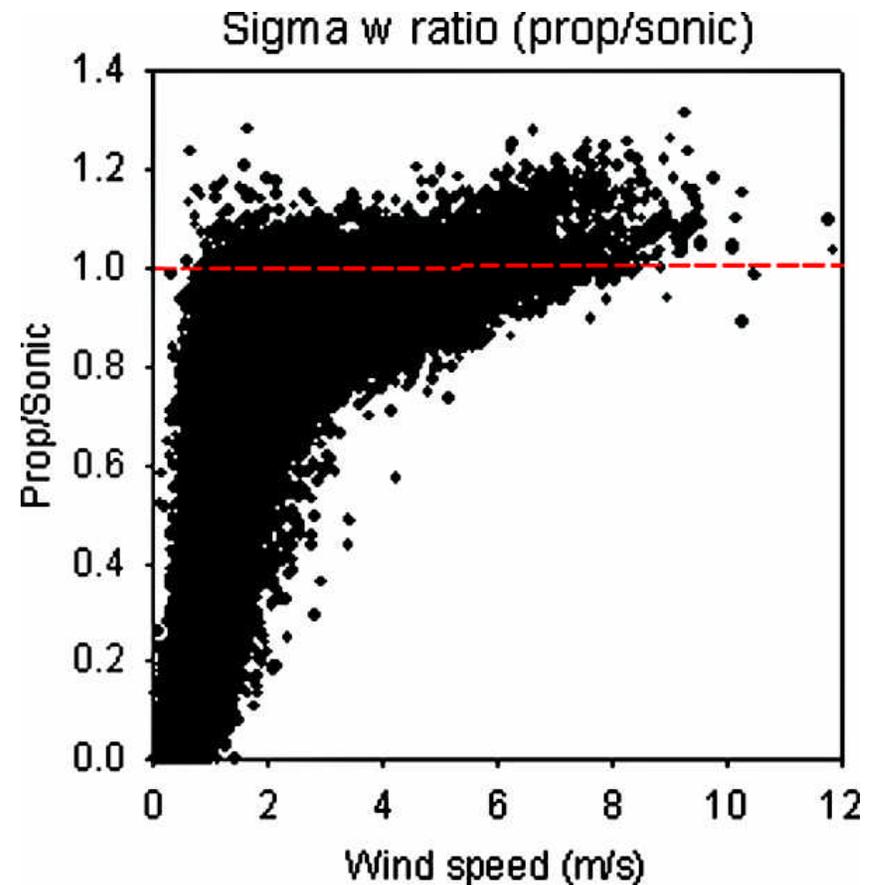
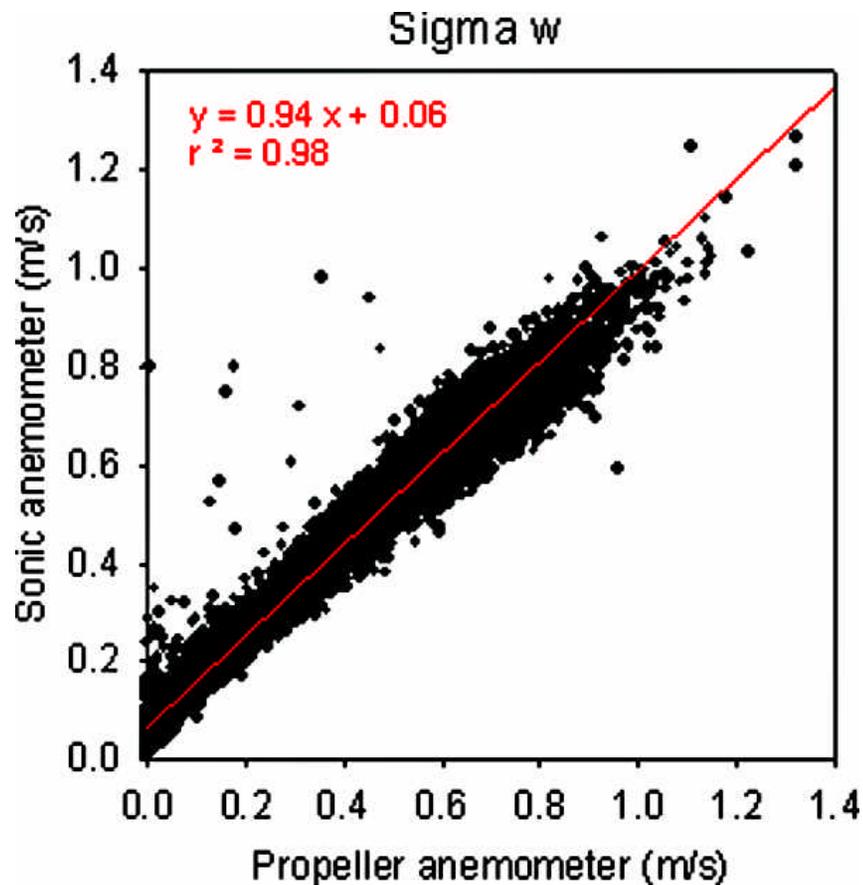
Large bias if $u < 1.5$ m/s



Variable bias if $u < 1.5$ m/s



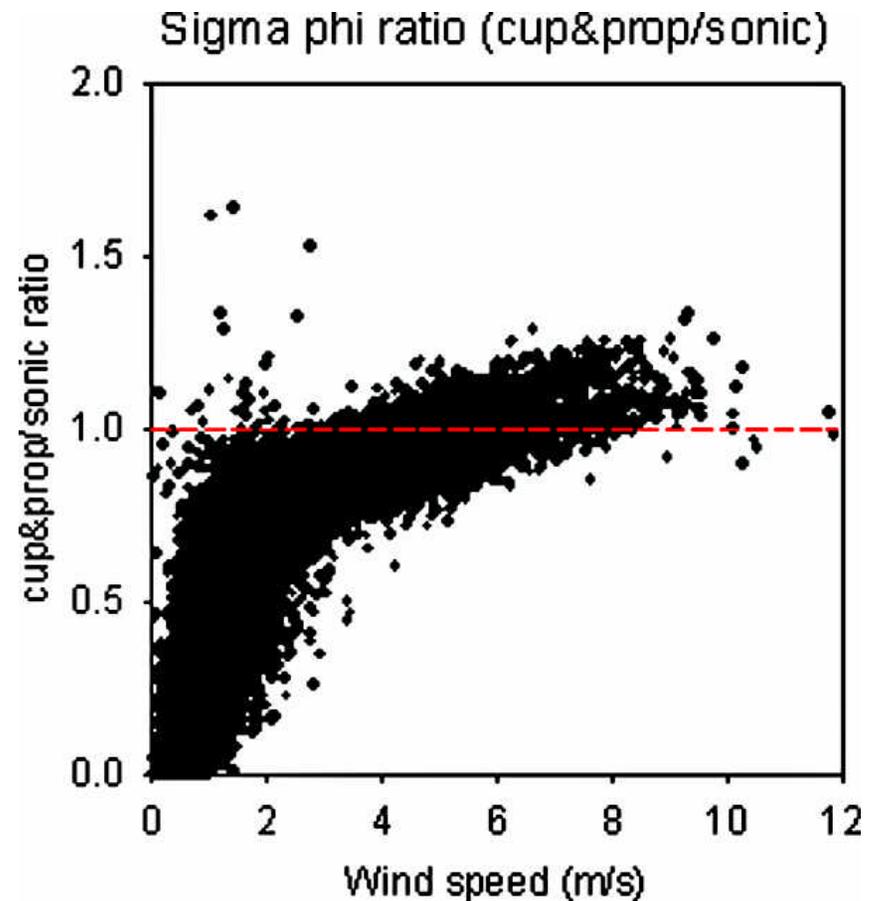
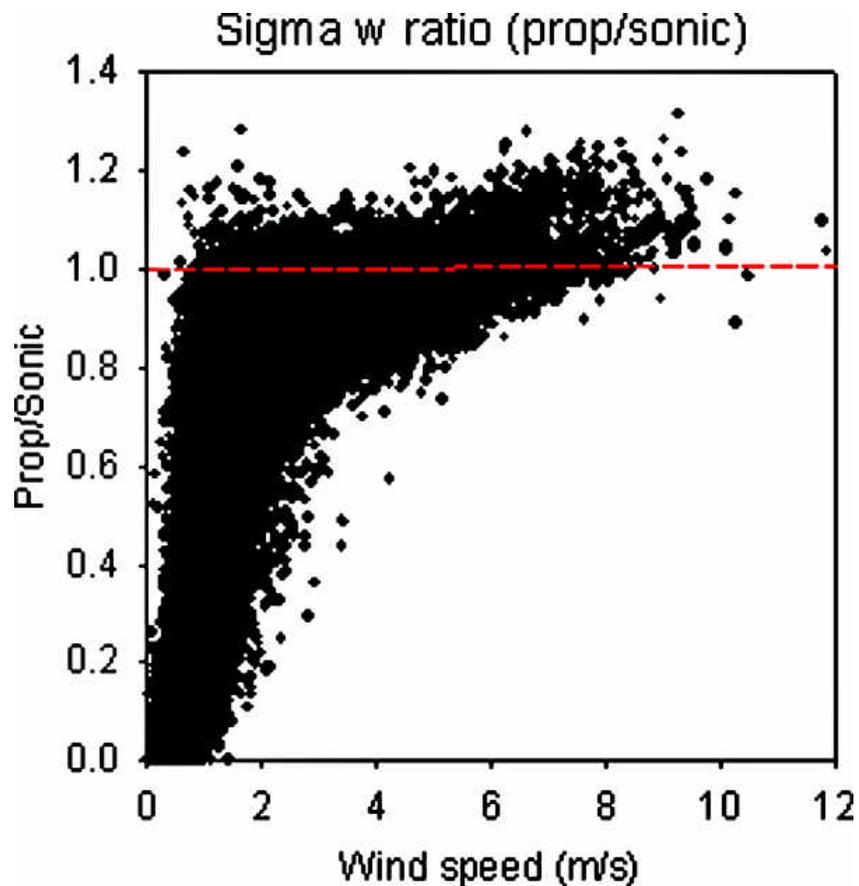
σ_w Correlation and Ratios



Good over-all correlation... But large bias at low speeds

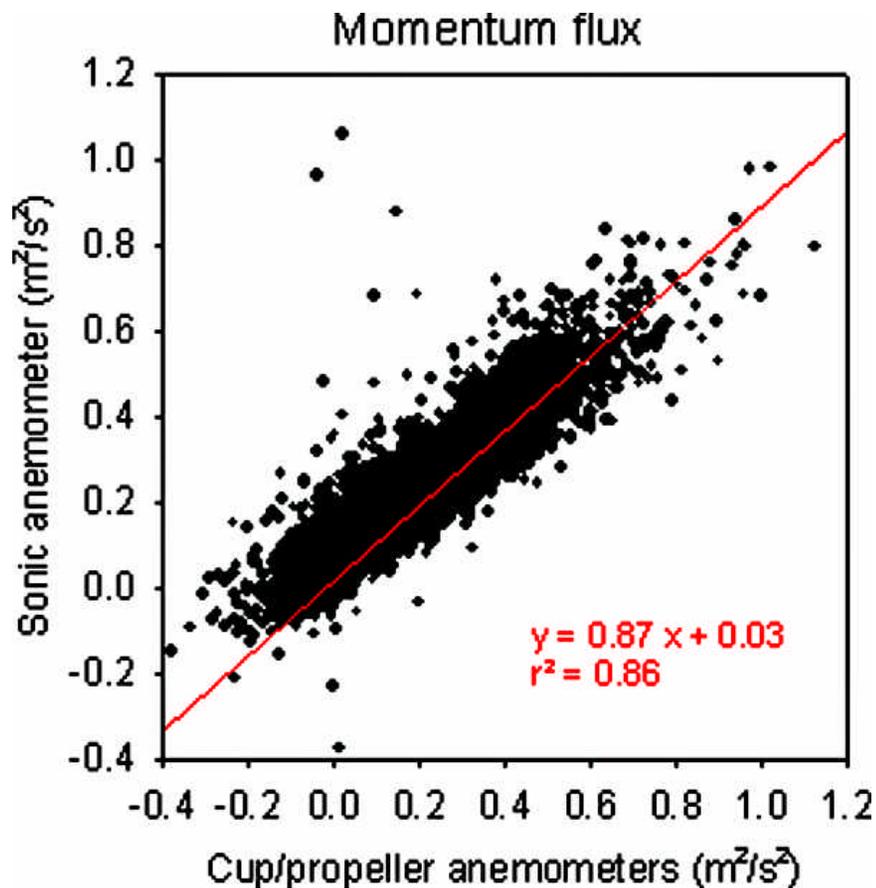


σ_w and σ_ϕ Ratios



Mechanical sensors < responsive at low speeds \Rightarrow large bias

Fluxes



- **Now estimating (using eddy correlation):**
 - Sensible heat flux (from sonic measurements)
 - Evaporative heat flux & evaporation (from sonic & H₂O gas analyzer)

Summary Table



Variable/ parameter	r^2	Median Mechanical Sensors/Sonic ratio			
		All winds	≥ 2 m/s	< 2 m/s	< 1 m/s
Wind speed (u)	0.966	1.06	1.03	1.16	1.24
Peak wind gust	0.922	1.02	1.00	1.07	1.12
Sigma u (σ_u)	0.98	0.95	0.94	0.98	1.08
Sigma theta (σ_θ)	0.84	1.05	1.07	1.00	0.94
Sigma W (σ_W)	0.98	0.83	0.91	0.47	0.10
Sigma phi (σ_ϕ)	0.56	0.78	0.88	0.42	0.08
Momentum flux ($-\overline{u'w'}$)	0.86	0.74	0.89	0.02	0.00

Summary



- **Sonic vs. mechanical sensor measurements:**
 - Good agreement for stronger winds (σ_w bias: 1.25 factor)
 - Better measurements for light winds (large % differences)
 - Errors especially large for vertical turbulence \Rightarrow
 - sonic σ_ϕ : 5-10 $^\circ$ greater when cup/prop $\sigma_\phi < 5^\circ$
 - large (factors of 2-10+) errors in σ_z estimates
- **Sonic anemometer limitations:**
 - Data loss from wetting (rain/fog with light winds)
 - Needs more power (110 mA): 10X cup/vane; 20X vert. propeller
- **Ideal supplement & backup to routine measurements**