EUMeTrain Wind Event Week 2022

Ground-based wind measurements

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Why wind ?

- Routine meteorology, research, aviation, air quality, hazard …
- Vector, small scale (random, spatial & temporal) fluctuations superimposed on larger-scale organized flow
- Minimum i.e., routine information: average horizontal components (or speed & direction) variability („gustiness“)
- Research: turbulence characteristics (100 Hz) (exchange processes)

Ground-Based Wind Measurements

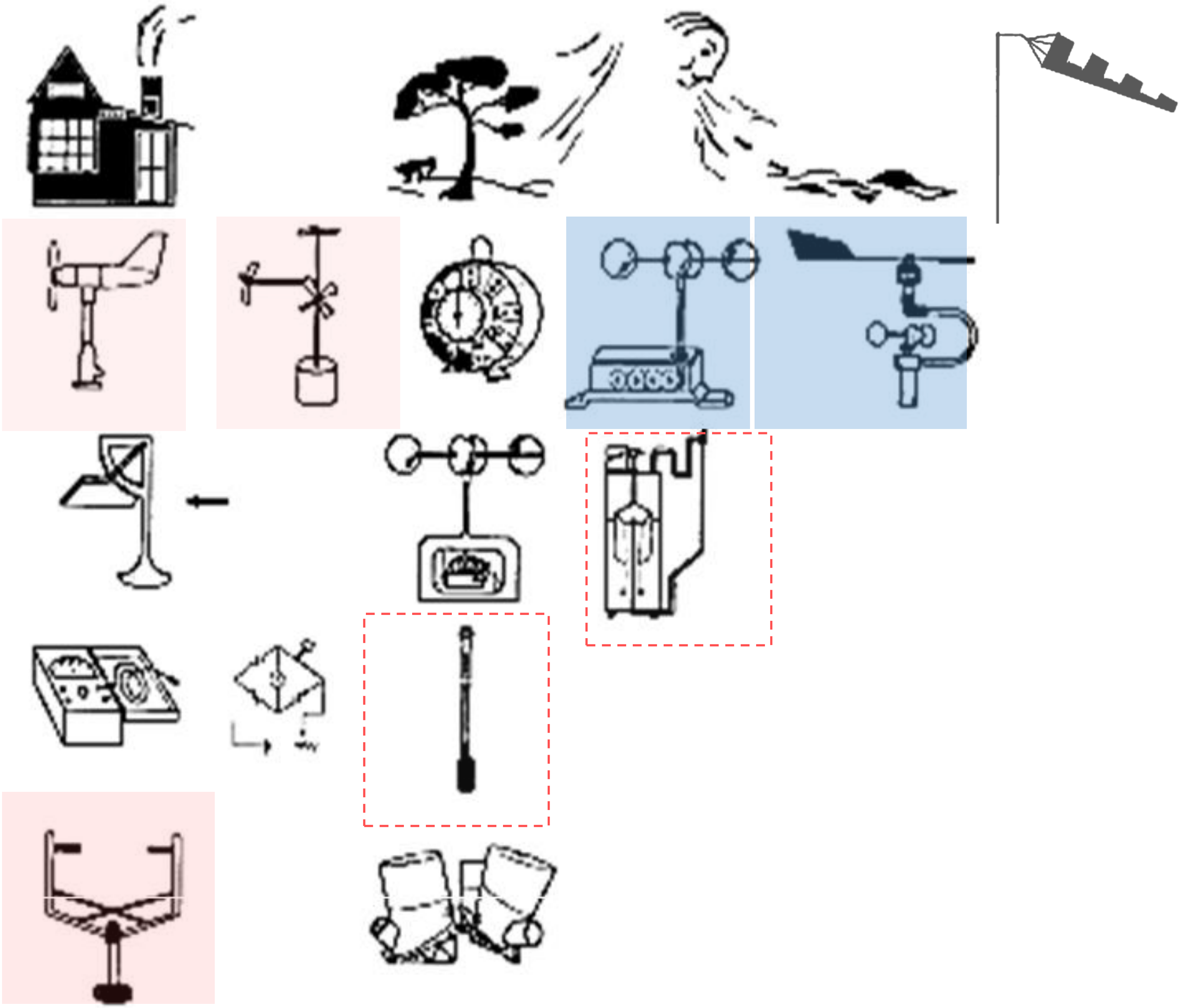
Indicators

Rotating

Pressure

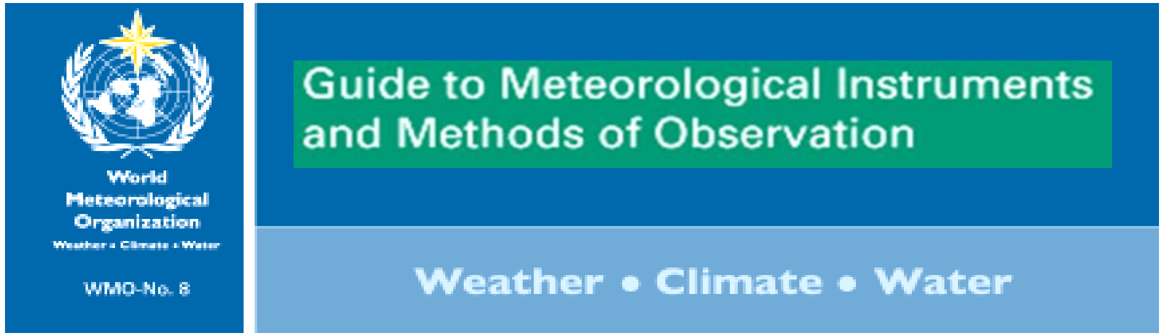
Hot wires

Sonics



[8]

WMO



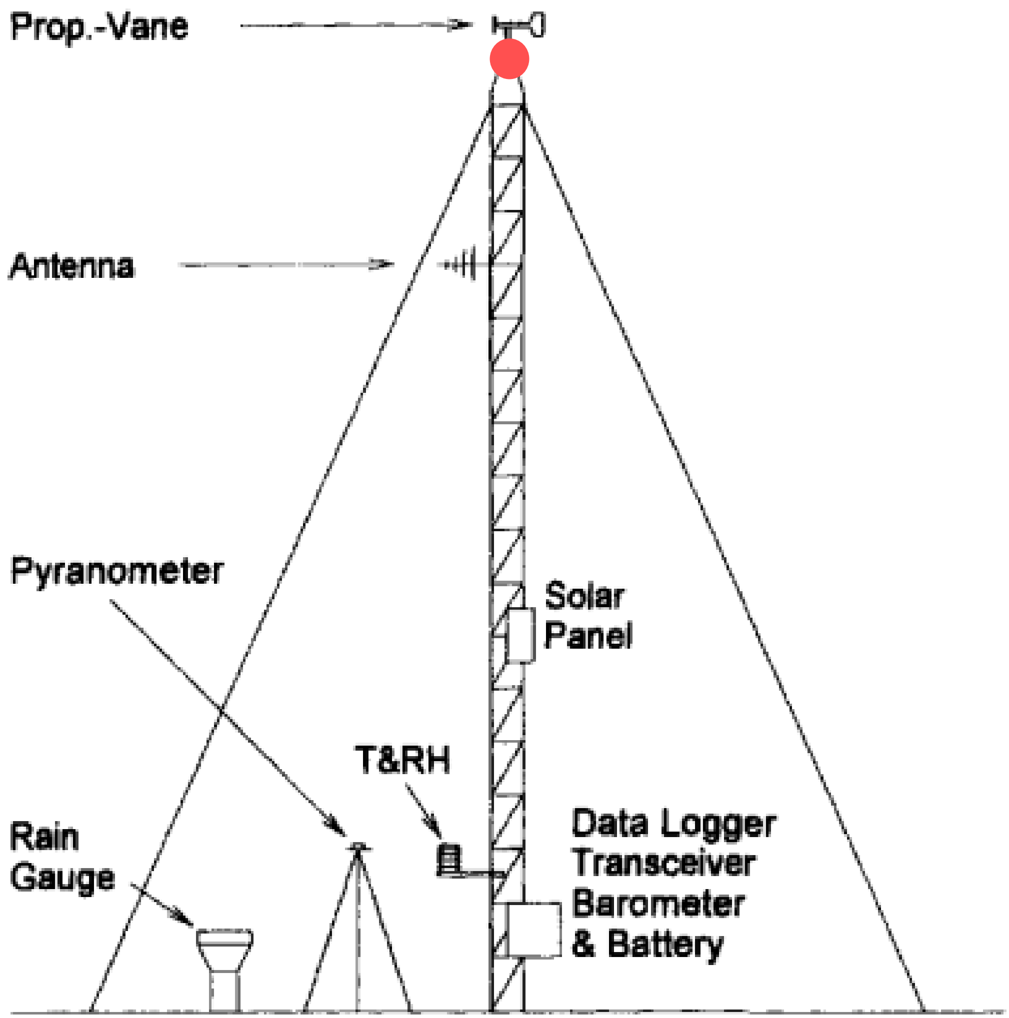
- 10 m agl. or 10 m above nearby obstacles
- 10-min averages from 1-min samples, plus standard deviation

  peak gust in the last full hour

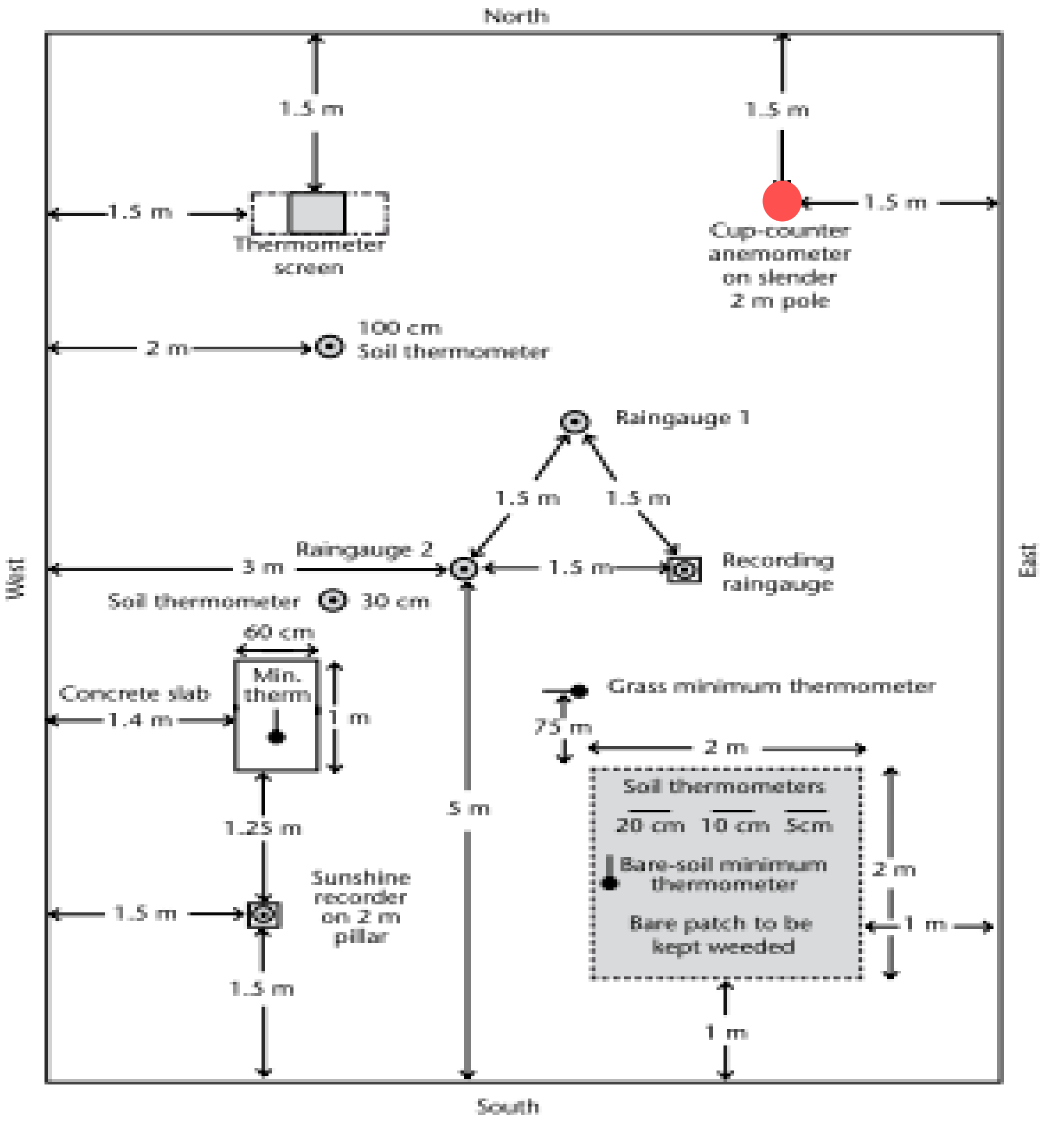
  (aviation, air quality: 3-sec peak gust)
- Resolution $\pm$ 0.5 ms^{-1}; degrees to the nearest 10°
- “Calm” =: average wind speed < 1 kn (direction coded as 00).
- Can be achieved using vane and cup/propeller anemometer

[2]

WMO, EPA ....



Prop.-Vane
Antenna
Pyranometer
Solar Panel
T&RH
Data Logger Transceiver Barometer & Battery
Rain Gauge

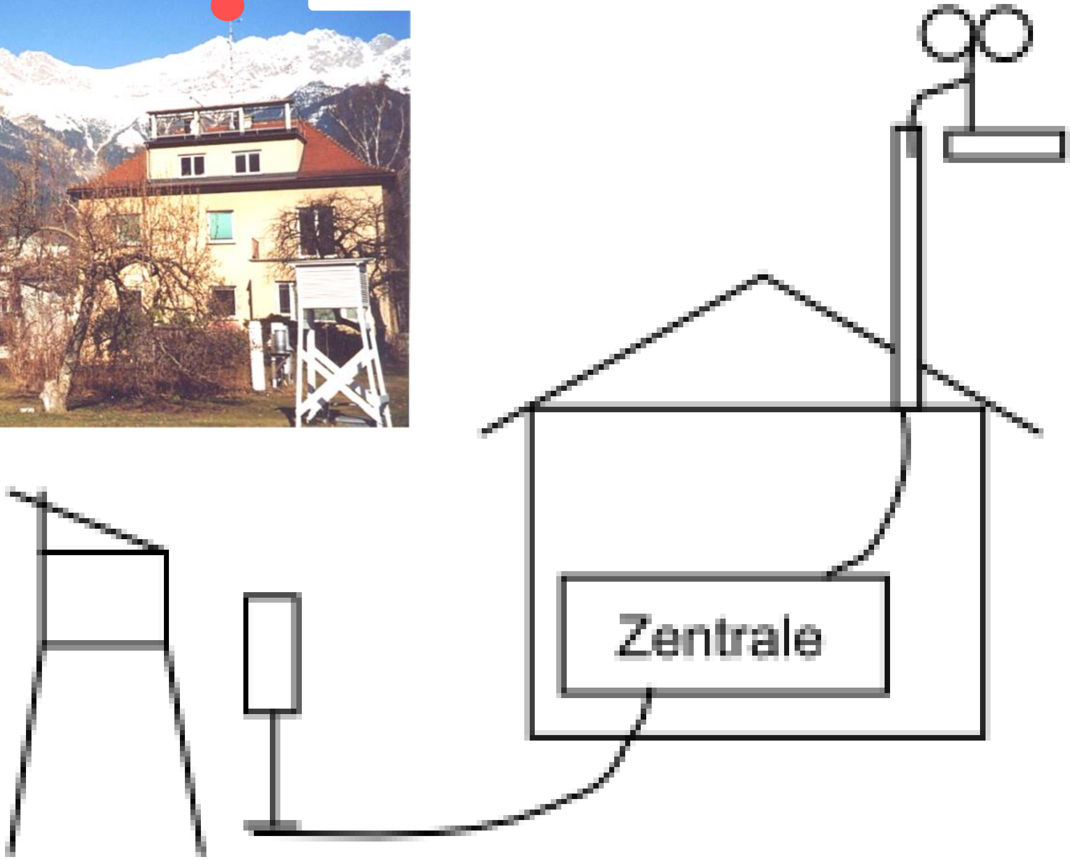


North
South
West
East
1.5 m
Thermometer screen
Cup-counter anemometer on slender 2 m pole
2 m
100 cm Soil thermometer
Raingauge 1
Raingauge 2
Recording raingauge
3 m
Soil thermometer 30 cm
60 cm
Min. therm
Concrete slab
1.4 m
1 m
Grass minimum thermometer
75 m
5 m
1.25 m
Soil thermometers
20 cm 10 cm 5cm
Bare-soil minimum thermometer
Bare patch to be kept weeded
Sunshine recorder on 2 m pillar

[1], [2]

ZAMG (TAWES-UIBK)

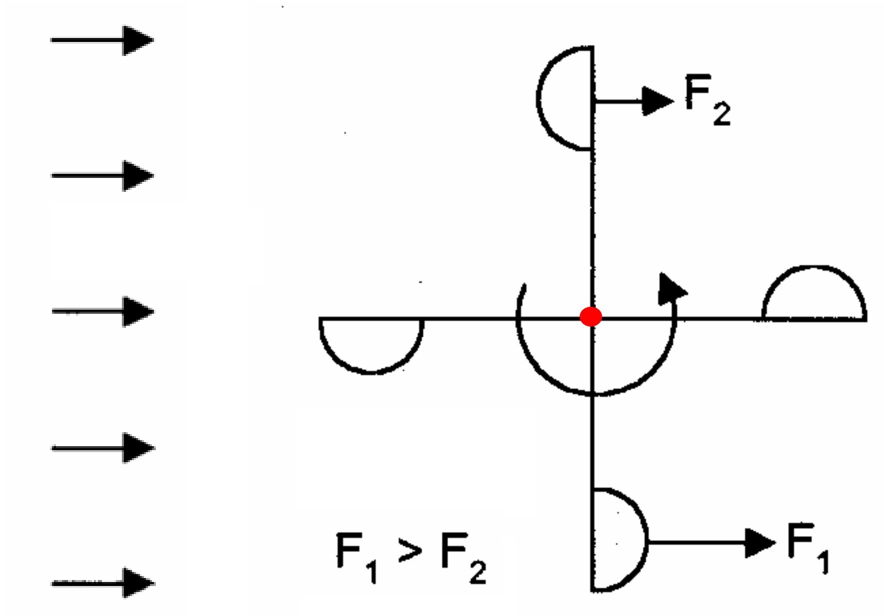
1971-1986



since 1986

Cup anemometers

- Principle



$$v = u.\frac{\sqrt{c_{concave}} + \sqrt{c_{convex}}}{\sqrt{c_{concave}} - \sqrt{c_{convex}}} \approx 4\,.\,u$$

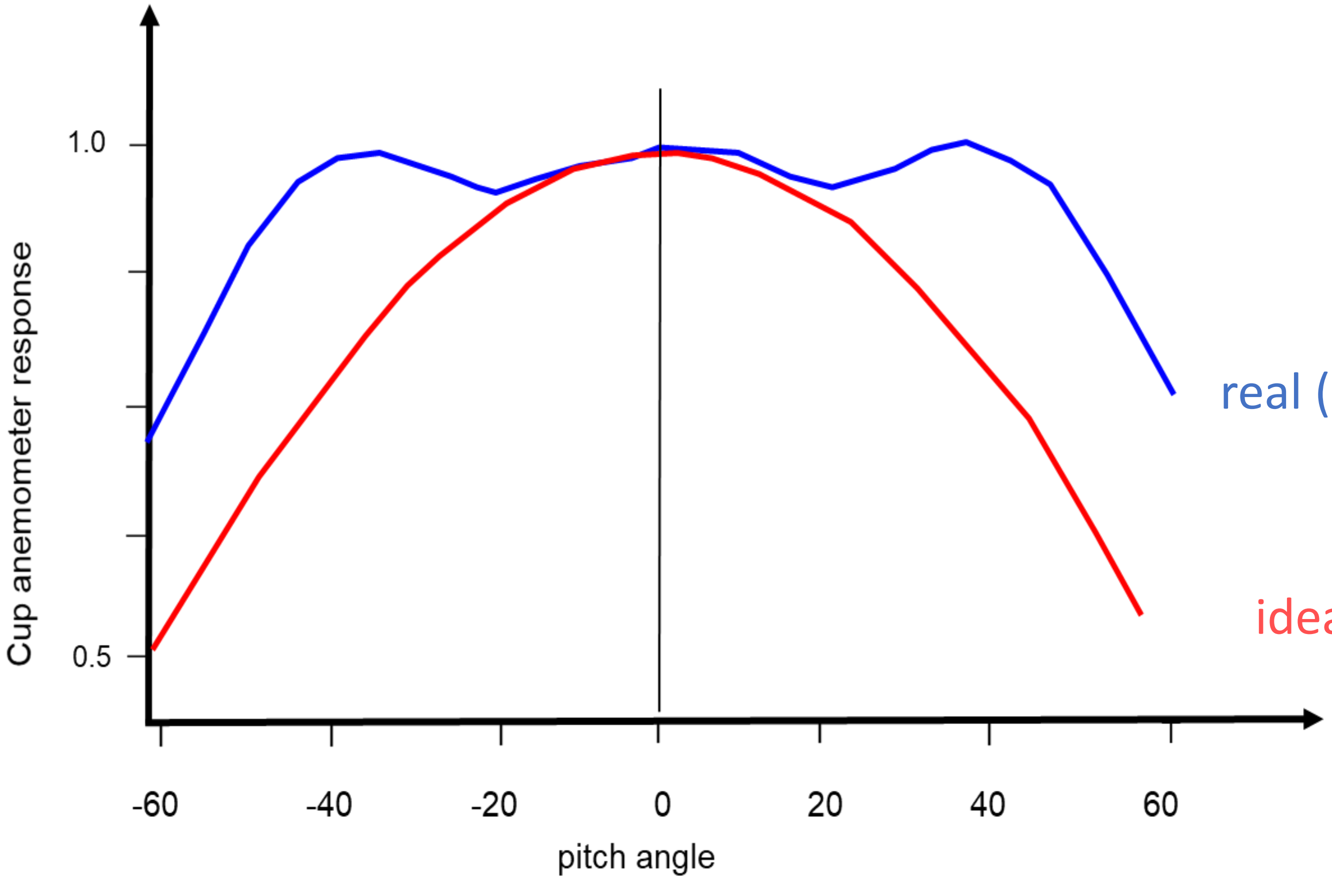
$$v = a + b.u$$

→ Robust, independent of direction, different signals to be recorded, WMO-conform

→ Need to (re-)calibrate, threshold velocity, icing, tilt effects (cosine), overspeeding

Cup anemometers

„Tilt“ effects (static error)



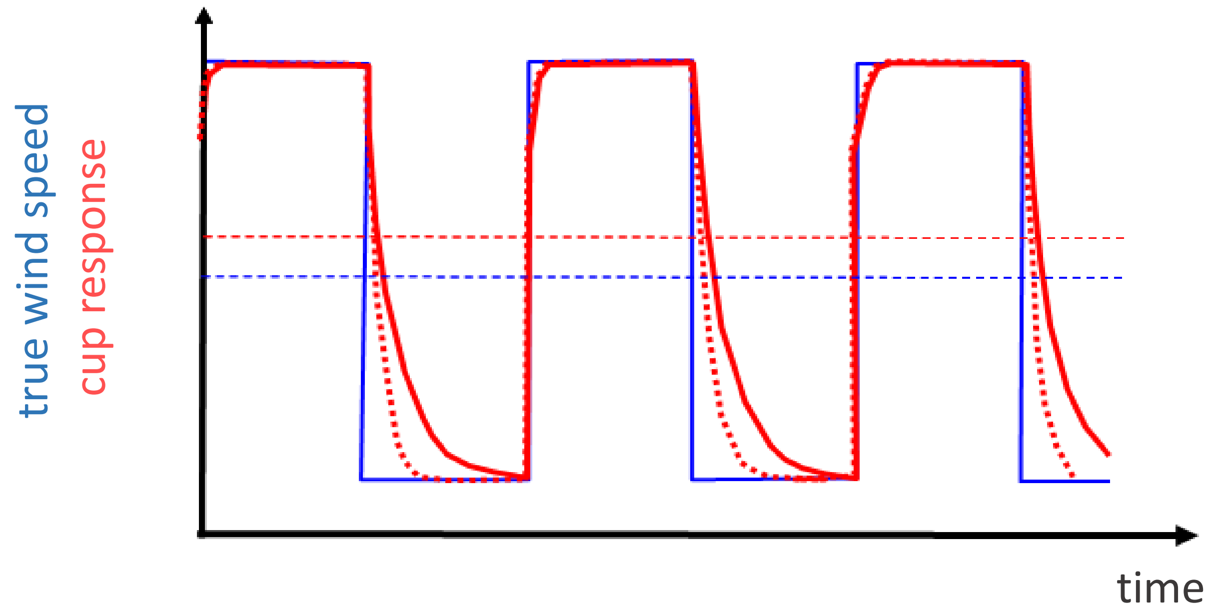
real (depending on cup characteristics)

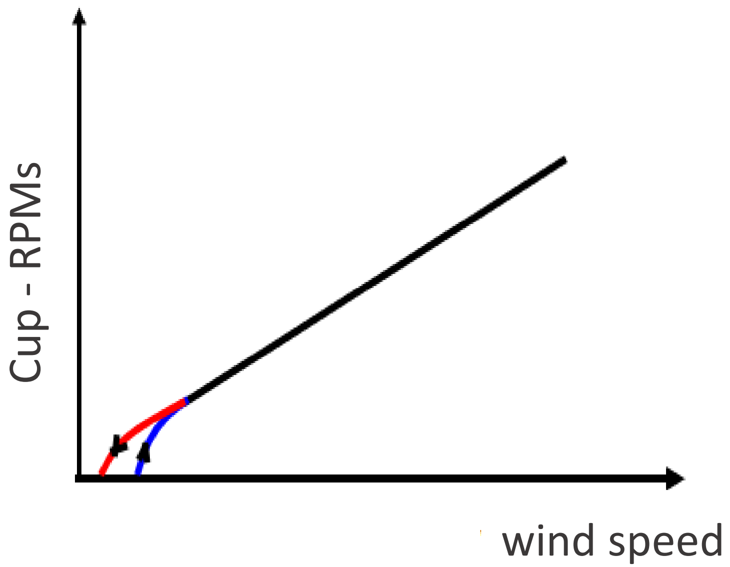
ideal ($V_{cup} = |V_a| \cos \alpha$)

→ Overestimation different for each sensor, align sensor horizontally; slopes ?

Cup anemometers

„Overspeeding“ (dynamic error)





→ Overstimation depends on: cup characteristics (mass, shape, dimensions)

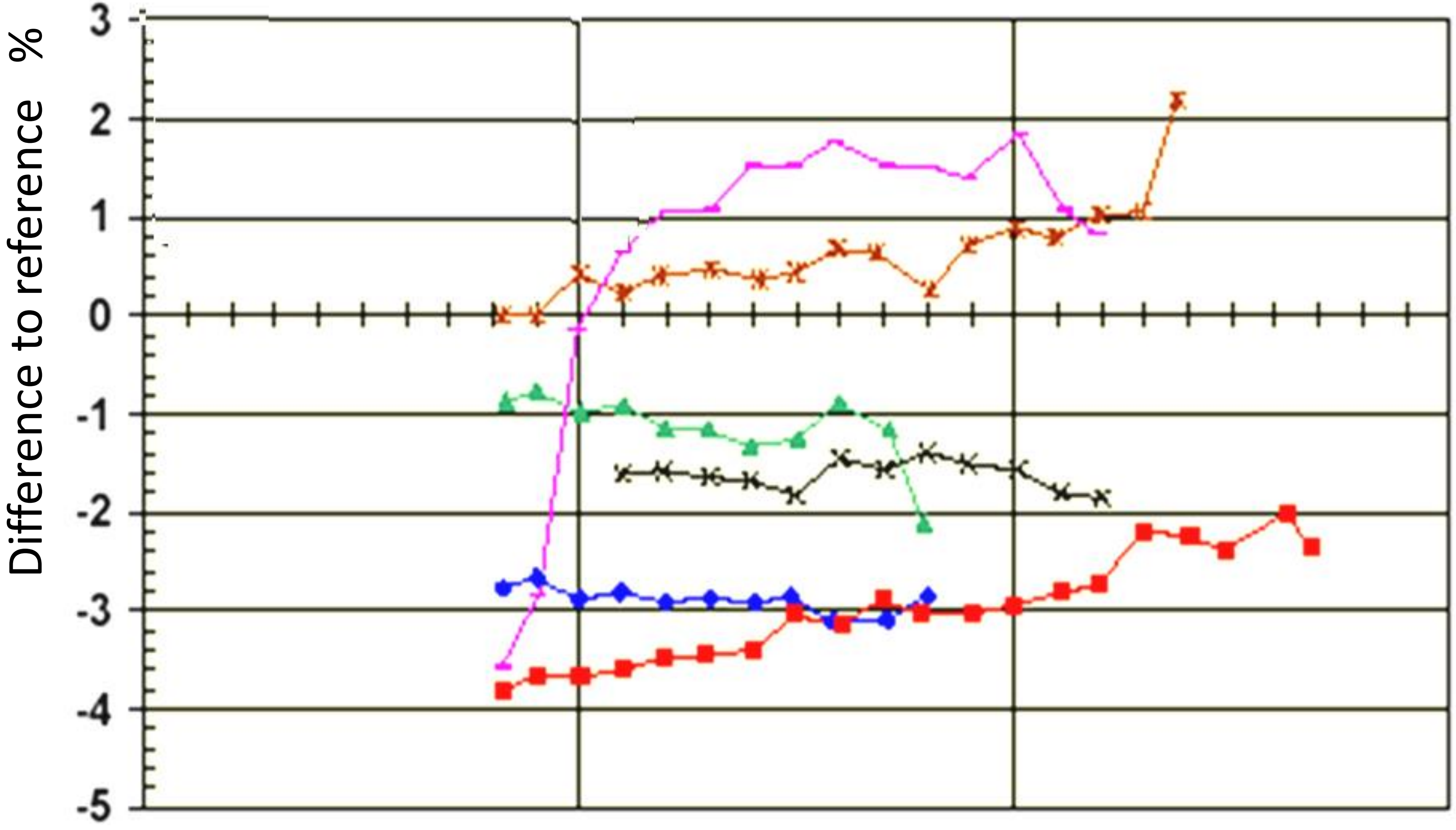
speed and gust characteristics

>30%, not corrected !

$$\tau = \frac{I}{\rho R^2 C_D A v_a} = \frac{\lambda}{v_a}$$

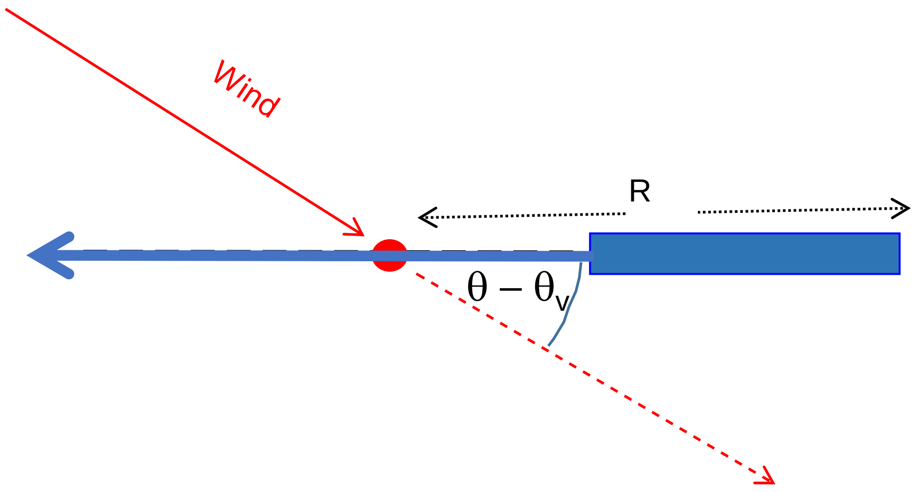
→ Select according to needs (> τ, λ) ; tradeoffs (mass vs. robustnes)

Field intercomparisons



Wind vanes

- Measurement principle:



$$I \cdot \frac{\partial^2\theta}{\partial t^2} + \frac{N.R}{v}\frac{d\theta}{dt} = -N\left(\theta - \theta_v\right)$$

→ response depends on: mass (inertia)

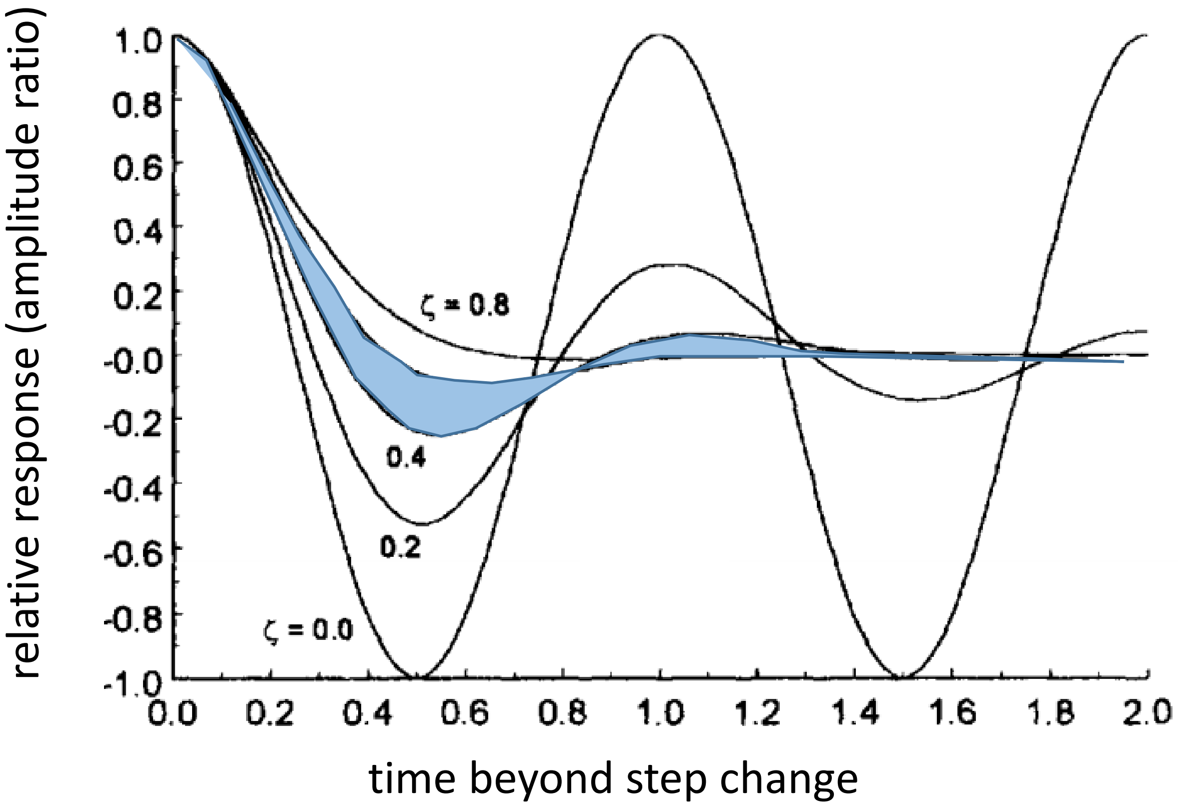
dimensions and geometry, statically balanced, friction

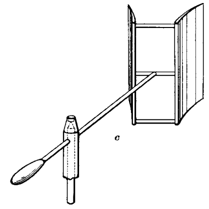
wind speed

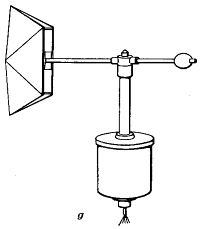
aerodynamic torque $N = \frac{1}{2} C_L \, \rho \, A \, v^2 \, R$

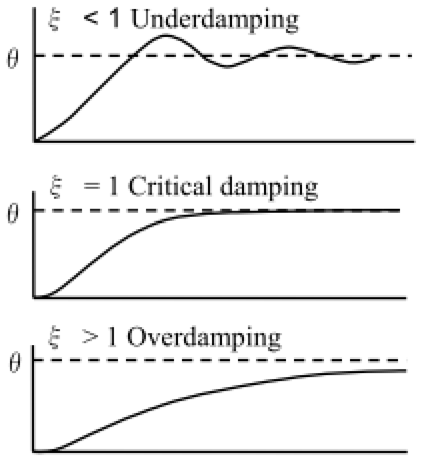
Wind vanes

Response to step changes









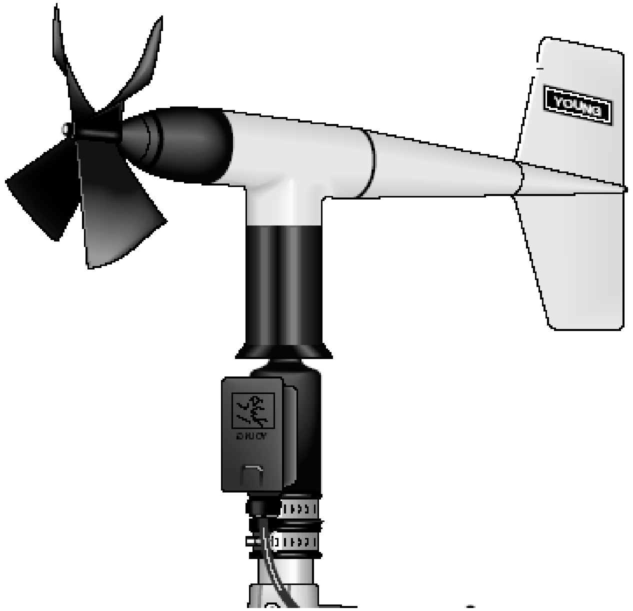
→ select according to needs

→ WMO: ξ ~ 0.3 – 0.7 („damping ratio" =: actual damping vs. critical value)

[2]

Propeller anomometer

- Combined sensor
- Measurement principle: $v = u \cot(\alpha - \psi)$

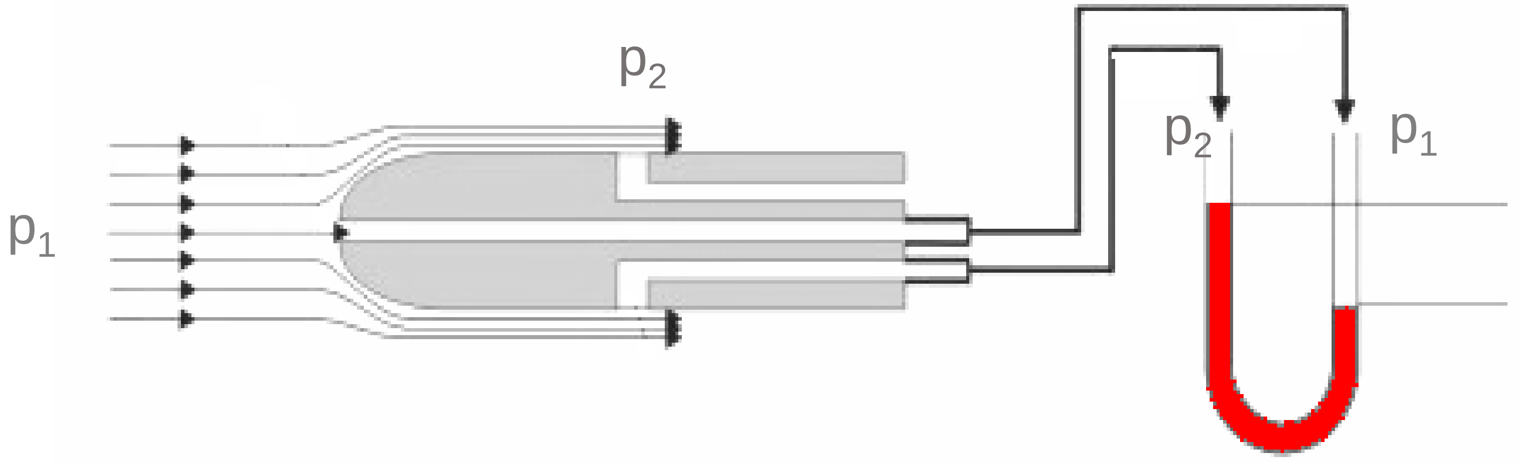


→ opt for harsh alpine/marine conditions (axis torque), 3-components

→ higher threshold velocity, directional response, yaw & tilt effects (underestimates)

[6] [9]

Pitot (Prandtl)- probe



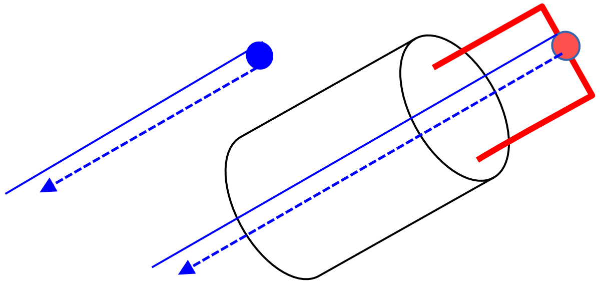
$$p_1 - p_2 = \frac{\rho . v^2}{2}$$

$$\rightarrow \quad v = \sqrt{\frac{2(p_1 - p_2)}{\rho}}$$

- Robust, small, 1st-order principle i.e., reference
- Directional dependency, icing, less sensible at low velocites
- Applications: aviation (v, p, z), laboratory

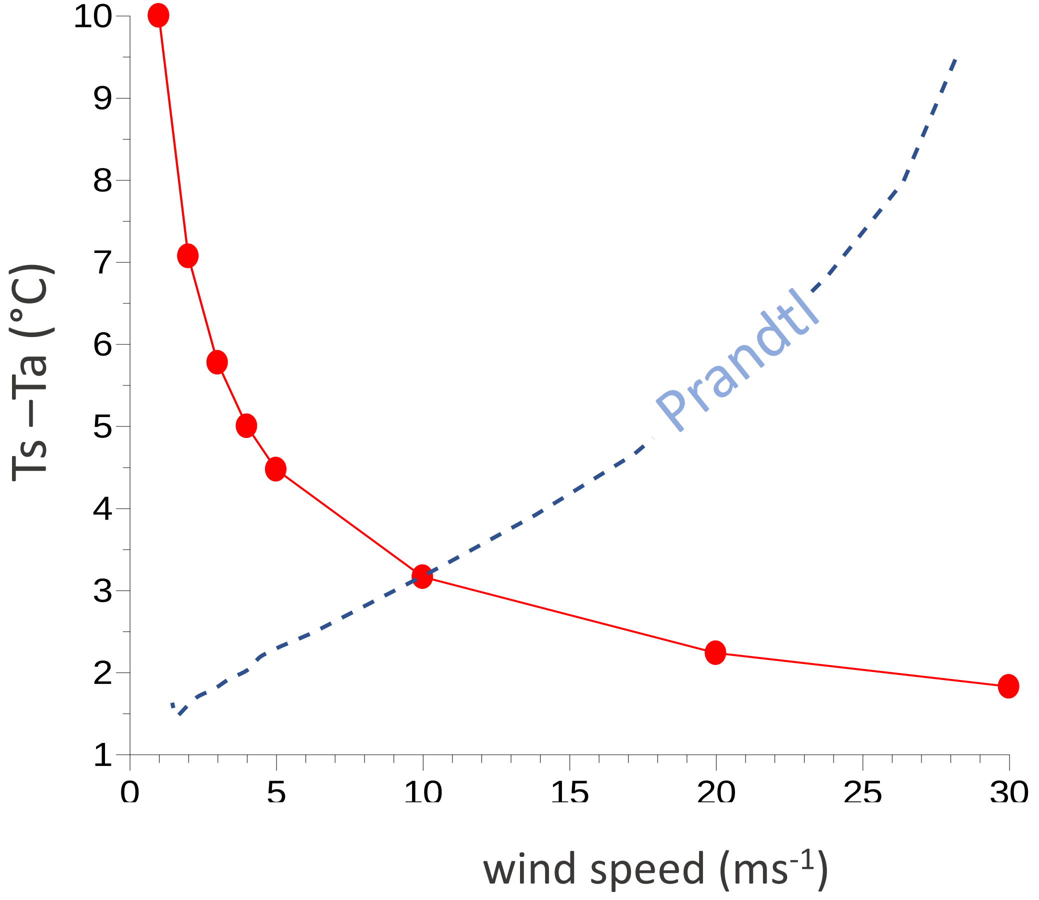
Hot wire anemometers

Measurement principle



$$P = I^2 R = \alpha_L (Ts - Ta)$$

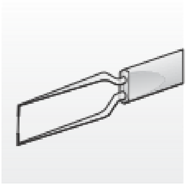
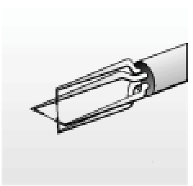
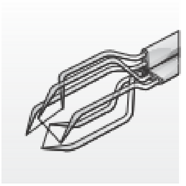
$$\alpha_L \propto \sqrt{v} \rightarrow \quad Ts - Ta \propto \frac{P}{\sqrt{v}}$$



→ Robust, 1st order principle i.e., reference, no moving parts

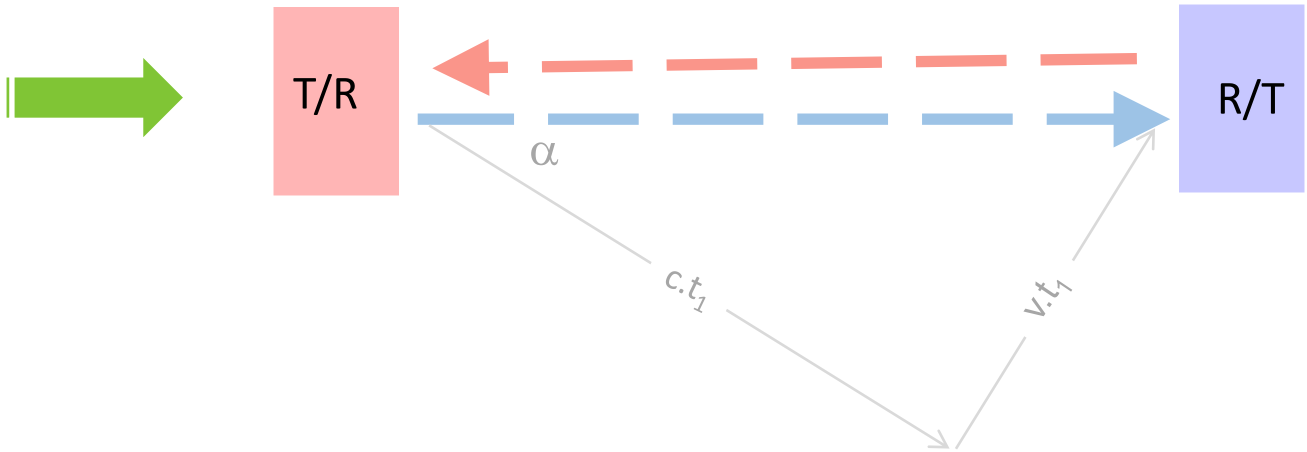
→ Sensible at low velocites, directional sensitivity, not robust, dry

→ Applications: lab, engineering, turbulence

Sonic anemometers

Measurement principle:



$$t_1 = \frac{d}{c.\cos\alpha + v} \qquad t_2 = \frac{d}{c.\cos\alpha - v}$$

$$\alpha = 0^\circ \rightarrow \quad v = \frac{d}{2}\left(\frac{1}{t_1} - \frac{1}{t_2}\right)$$

→ Fast response (100 Hz), low threshold, 2d or 3d components, no moving parts

→ Expensive (costs, maintenance, postprocessing)

→ Applications: lab, turbulence (w’, T_v’), replacing cups

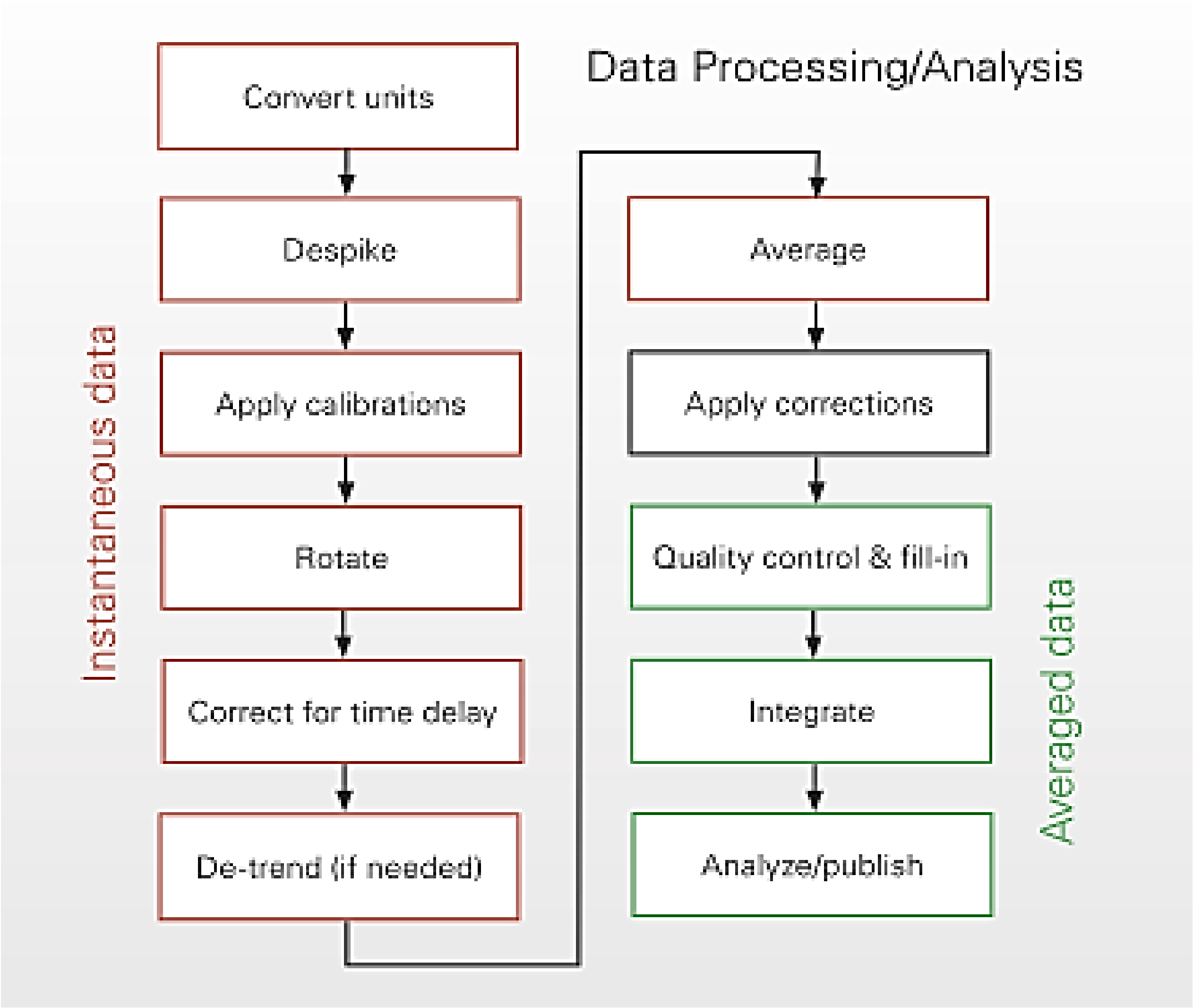
Sonic anemometers

Turbulence measurements, Eddy-Covariance Method to determine fluxes

$$\tau = -\rho \overline{w'u'}$$

$$F = \rho c_p \overline{w'\theta'}$$

$$L = \rho L_v \overline{w'q'}$$



[3]

Example cup anemometer

WIND SPEED SPECIFICATION SUMMARY

Range	0 to 50 m/s (112 mph), gust survival 60 m/s (134 mph)
Sensor	12 cm diameter cup wheel assembly, 40 mm diameter hemispherical cups
Turning Factor	75 cm (2.46 ft)
Distance Constant	2.3 m (7.5 ft) (63% recovery)
Threshold	0.5 m/s (1.1 mph)
Transducer	Stationary coil, 1300 ohm nominal resistance
Transducer Output	AC sine wave signal induced by rotating magnet on cup wheel shaft 100 mV p-p at 60 rpm. 6V p-p at 3600 rpm.
Output Frequency	1 cycle per cup wheel revolution.

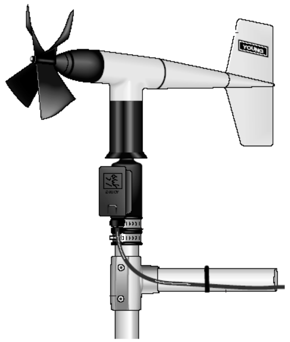
WIND DIRECTION (AZIMUTH) SPECIFICATION SUMMARY

Range	360° mechanical, 352° electrical (8° open)
Sensor	Balanced vane, 16 cm turning radius.
Damping Ratio	0.2
Delay Distance	(50% recovery) 0.5 m (1.6 ft)
Threshold	0.8 m/s (1.8 mph) at 10° displacement
Transducer	Precision conductive plastic potentiometer, 10K ohm ±20% resistance 1.0% linearity, life expectancy 50 million revolutions Rated 1 watt at 40°C, 0 watts at 125°C
Transducer Excitation	Requirement Regulated DC voltage, 15 VDC max
Transducer Output	Analog DC voltage proportional to wind direction angle with regulated excitation voltage applied across potentiometer

→ we use it for teaching purposes

[5]

Example propeller anemometer



Wind speed

Range:	0-134 mph (0-60 m s^{-1})
Accuracy:	±0.6 mph (±0.3 m s^{-1})
Starting threshold:	2.2 mph (1.0 m s^{-1})
Gust survival:	220 mph (100 m s^{-1})
Distance constant (63% recovery):	8.9 ft (2.7 m)
Output:	ac voltage (3 pulses/ revolution) 1800 rpm (90 Hz) - 19.7 mph (8.8 ms^{-1})

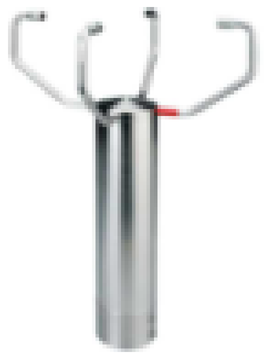
Wind direction

Electrical range:	0-360° mechanical, 355° electrical (5° open)
Accuracy:	±3°
Starting threshold	
at 10° displacement:	2.0 mph (0.9 m s^{-1})
at 5° displacement:	2.9 mph (1.3 m s^{-1})
Delay distance (50% recovery):	4.3 ft (1.3 m)
Damping ratio:	0.25
Damped natural wavelength:	24.3 ft (7.4 m)
Undamped natural wavelength:	23.6 ft (7.2 m)
Output:	Analog dc voltage from potentiometer - resistance 10 KΩ, linearity 0.25%, life expectancy 50 million revolutions.

→ we use it on glaciers

6]

Example TAWES –UIBK wind sensor



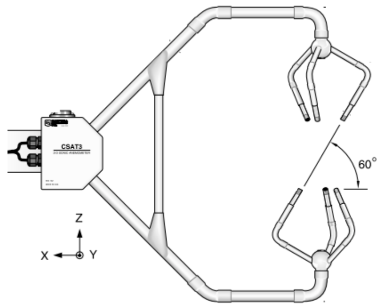
Wind speed	
Measuring range	0 … 85 m/s
Resolution	0.1 m/s (standard) 0.01 m/s (user defined)
Accuracy	±0.1 m/s rms (< 5 m/s) ±2 % rms (5 … 85 m/s)

Wind direction	
Measuring range	0 … 360 °
Resolution	1 ° 1 ° (standard) < 1 ° (user defined)
Accuracy	±1 ° @ WS 1 … 60 m/s ±2 ° @ WS 60 … 85 m/s
Virtual temp.	
Measuring range	-50 … +80 °C
Resolution	0.1 K
Accuracy	±0.5 K @ WS < 35 m/s

→ we use it for routine measurements

[7]

Example 3d-sonic anemometer



OUTPUTS: u_x, u_y, u_z, and c (u_x, u_y, u_z, are orthogonal wind components referenced to the anemometer head; c is the speed of sound)

SPEED OF SOUND: determined from 3 acoustic paths; corrected for crosswind effects

MEASUREMENT RATE: programmable from 1 to 60 Hz, instantaneous measurements; two oversampled modes are block averaged to either 20 Hz or 10 Hz

MEASUREMENT RESOLUTION: u_x and u_y are 1 mm s^{-1} rms; u_z is 0.5 mm s^{-1} rms; c is 15 mm s^{-1} (0.025 °C) with embedded code version 4 (standard) [c is 1 mm s^{-1} (0.002 °C) with embedded code version 3]; wind direction is 0.06 degrees rms. Values are the standard deviations of instantaneous measurements made of a constant signal. The noise is unaffected by the sample rate.

OPERATING TEMPERATURE RANGE: –30 to 50 °C (standard); –40 to 40 °C (cold shifted)

ACCURACY (–30 to 50 °C and –40 to 40 °C operating range; wind speed < 30 m s^{-1}; azimuth angles between ±170°):

Offset Error:

u_x, u_y:	< ±8 cm s^{-1}
u_z:	< ±4 cm s^{-1}

Gain Error:

Wind vector within ±5° of horizontal	< ±2 percent of reading
Wind vector within ±10° of horizontal	< ±3 percent of reading
Wind vector within ±20° of horizontal	< ±6 percent of reading

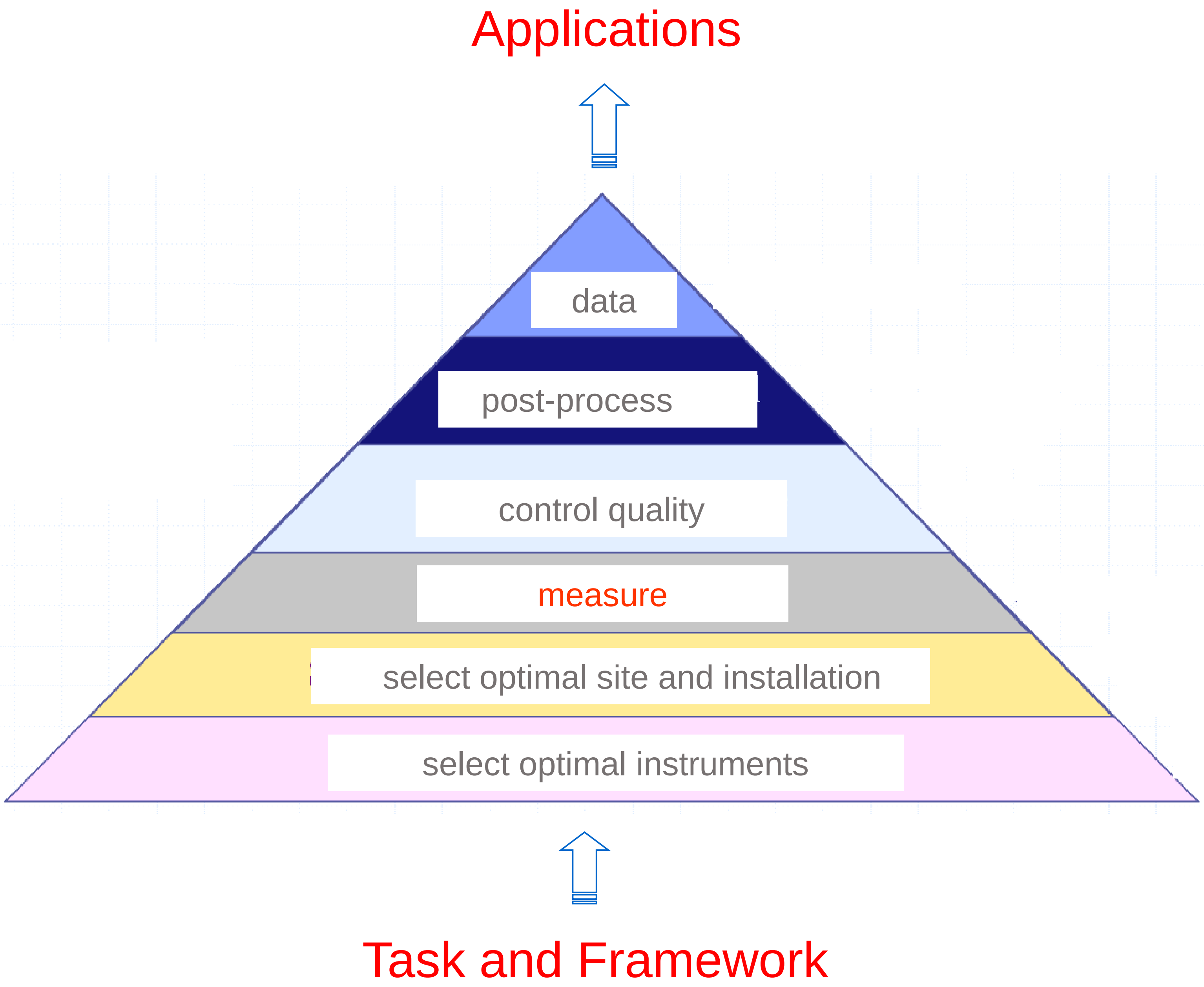
Wind Direction Accuracy:

±0.7° at 1 m s^{-1} for horizontal wind

→ we use it for turbulence and flux measurements

[4]

Methodical considerations



Conclusions

- Choose sensors according to investigation „problem“ (routine vs. turbulence)
- Watch critical specs: resolution, accuracy, power, signal, robustness
  threshold, response time, distance constant , damping ratio
- Observation site: constraints, representative (WMO vs. mast along building), footprint
- Installation: minimize disturbances
- Maintenance: trade-off (manpower/power supply, heating, robustness)
- Quality control: re-calibration, post-processing
- Metadata
- Sonics have certain advantages and may replace cups [10]
- Other types of sensors play more a role in research/engineering context

References

[1] World Meteorological Organization 2008: Guide to Meteorological Instruments and Methods of Observation,WMO-No. 8, ISBN 978-92-63-10008-5

[2] Brock, F. and Richardson S. 2001: Meteorological measurement systems, Oxford Univ. Press, 2001, 290p.

[3] Burba G. and D. Anderson 2010: A Brief Practical Guide to Eddy Covariance Flux Measurements: Principles and Workflow Examples for Scientific and Industrial Applications", LI-COR, Inc., 211p.

[4] https://www.campbellsci.cc/csat3

[5] https://www.campbellsci.com/03002-wind-sentry

[6] https://www.campbellsci.com/05103-l

[7] https://www.thiesclima.com/en/Products/Wind-Ultrasonic-Anemometer/?art=145

[8] https://www.jma.go.jp/jma/jma-eng/jma-center/ric/Our%20activities/International/CP4-Wind.pdf

[9] https://www.campbellsci.com/27106t-l

[10] Mauder, M. and Zeeman, M. J.: Field intercomparison of prevailing sonic anemometers, Atmos. Meas. Tech., 11, 249–263, https://doi.org/10.5194/amt-11-249-2018, 2018.

Thank you !