Advancing Atmospheric Turbulence Measurements with Multi-Path Ultrasonic Anemometers

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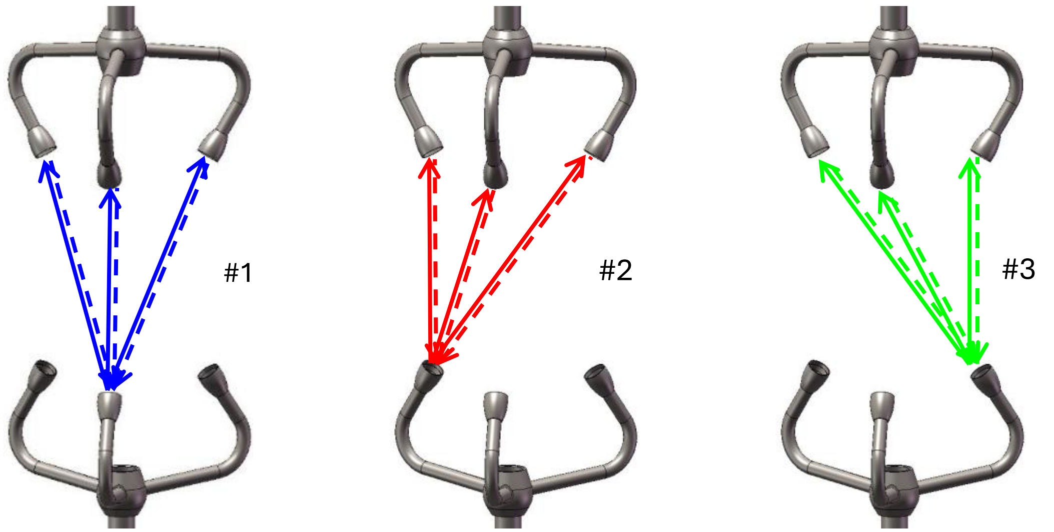
METEK GmbH, Germany



METEK
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Germany

25th Symposium on Boundary Layers and Turbulence

Sonic Technology

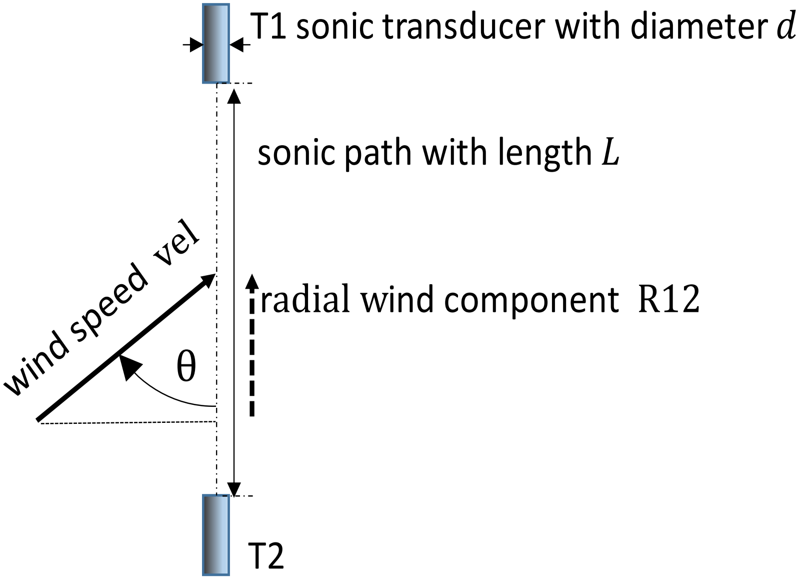
- Measuring accuracy of sonics is determined by:
  - Flow modification at transducer body („**shadow effect**“)
  - Flow modification at sensor head structure („**flow distortion**“)
- Data acceptance/data reliability check is required using objective criteria
- Data availability > 90 % for raw data also in adverse weather conditions

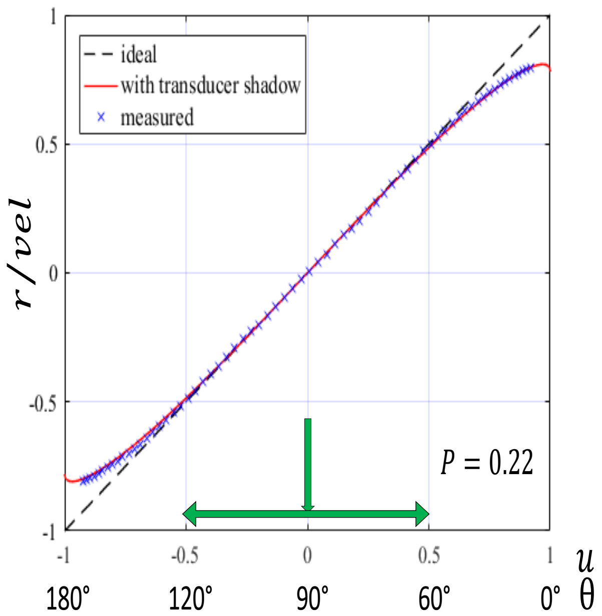
- Continuos evolution of used techniques required

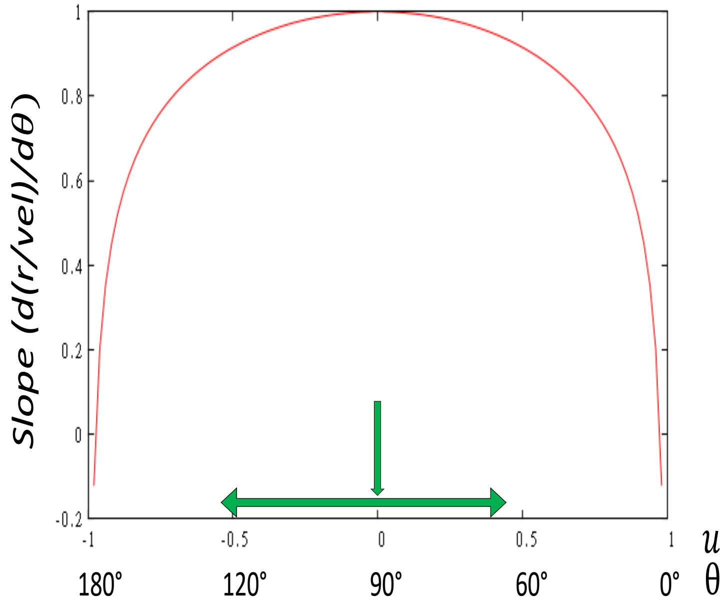
Shadow Effect

$$\frac{r}{vel} = u - u\,P\left(1 - \sqrt{1 - u^2}\right)$$ Wyngaard & Zhang

with $u = \cos\theta$ and $P = f(d/L)$







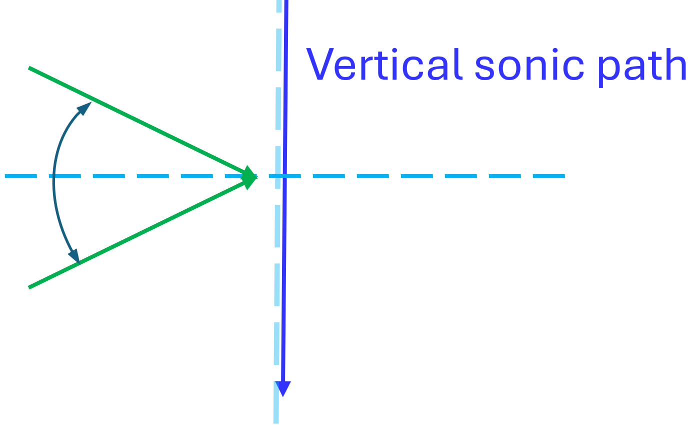
response function of shadow effect (left) and its first derivate (right)
green arrow indicates a vertically aligned measuring path in a horizontal flow

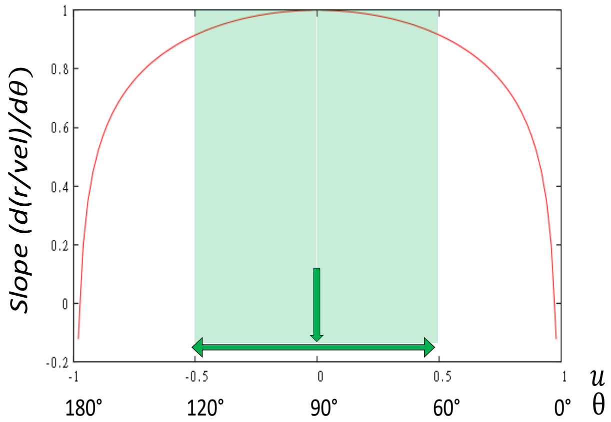
Sensor head structures

- Directional probes minimzes flows distortion for a wide inflow angle (sample below)
- Omni-Directional probes allow measurements from all sectors (samples below)

Shadow Effect

Vertical path 0°, assumed turbulent variation of inflow angle +- 30 °





Shadow Effect

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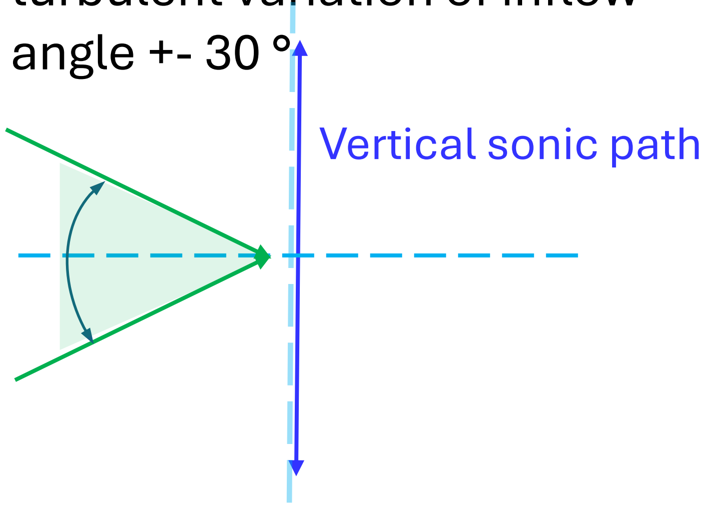
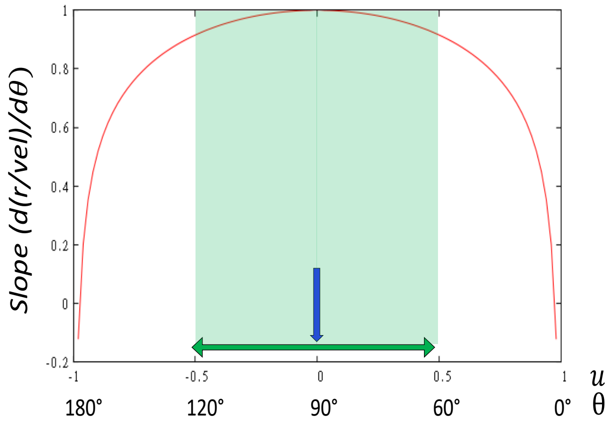
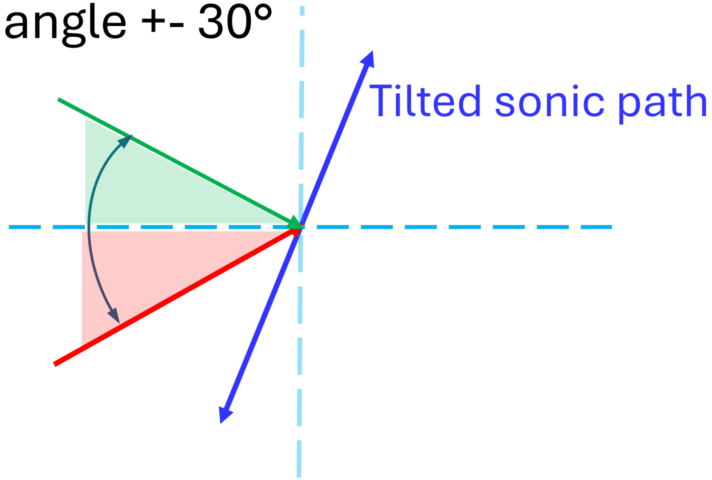
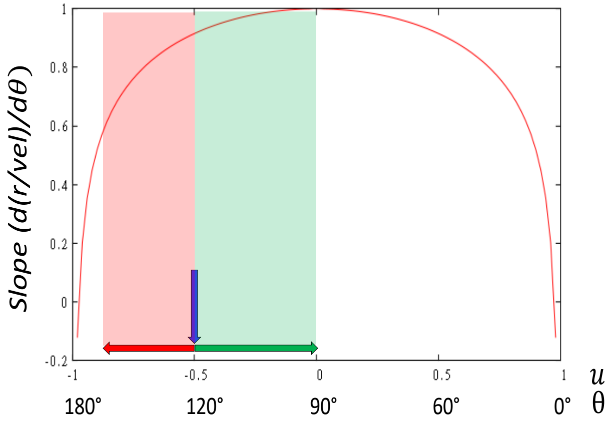


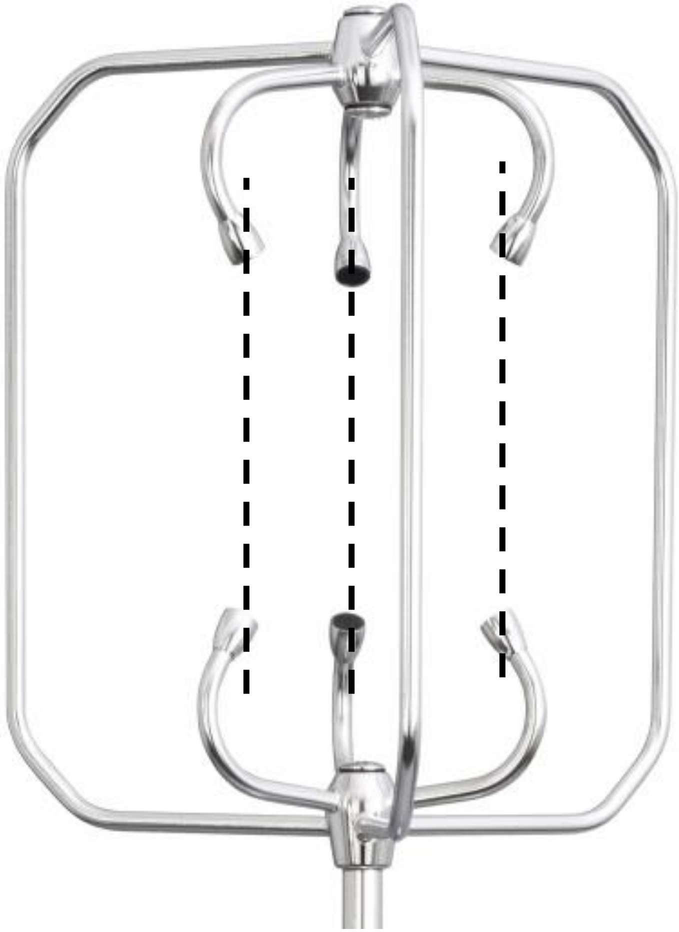


Tilted path 30°, assumed turbulent variation of inflow angle +- 30°





Can we compromise for the various effects?

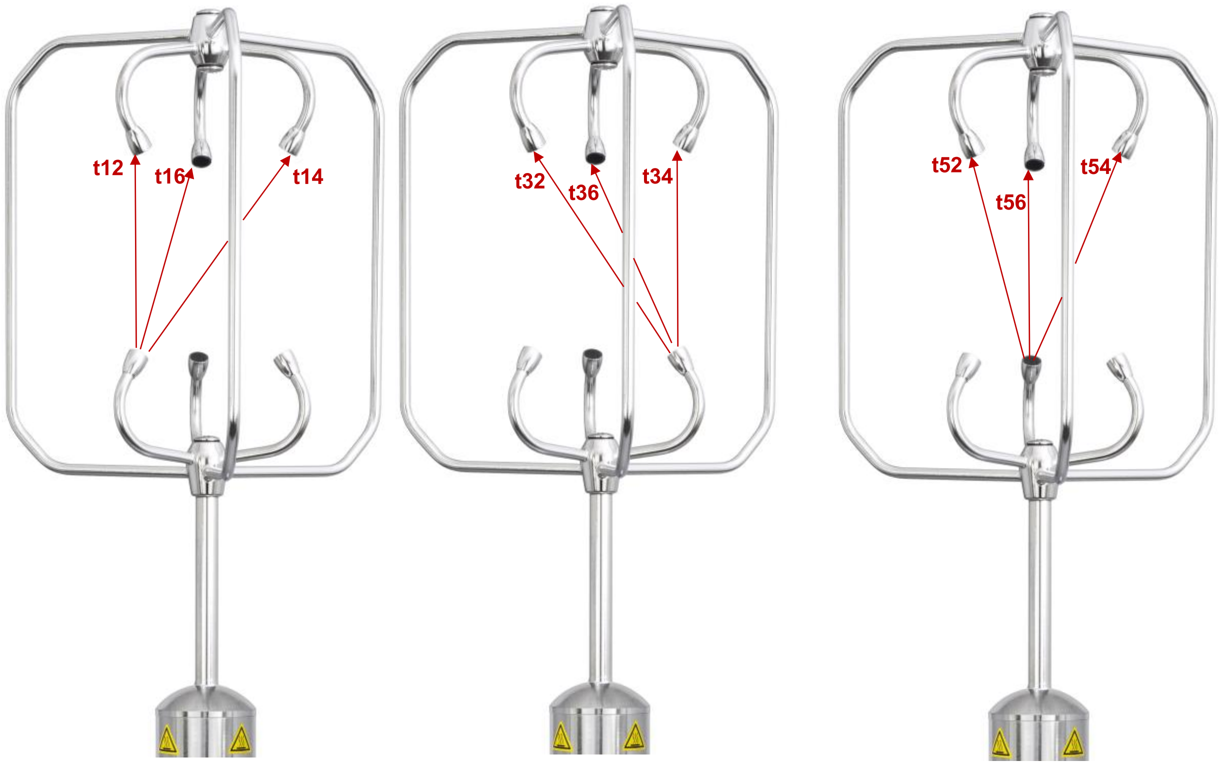


Multi-Path Approach

The transducer of the upper array are aligned vertically to the transducer of the lower array.

Each transmitter of one array communicates with all 3 receivers of the opposite array

Can we compromise for the various effects?

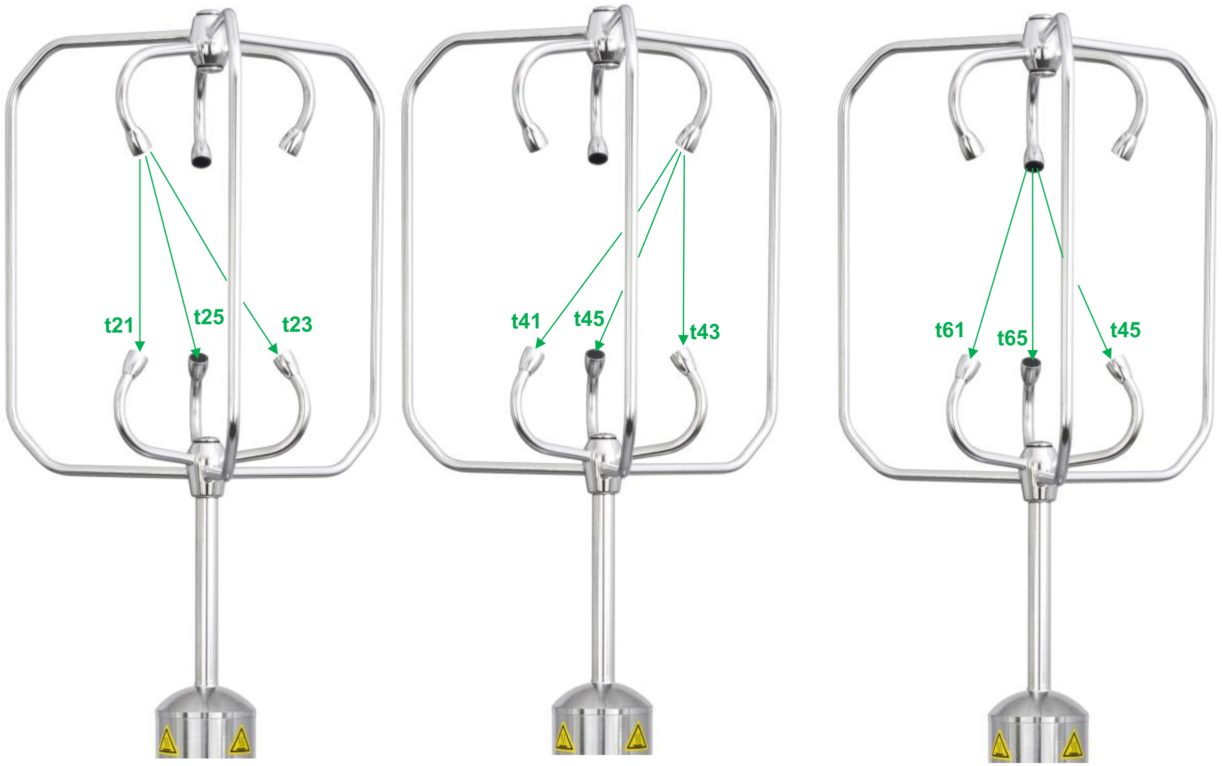


Multi-Path Sensors

- 3 x 3 measuring paths
- 6 tilted, 3 vertical radial winds
- 6 tilted, 3 vertical virtual temperatures
- Automatic derivation of x, y, z and Tv

(Side effect: redundancy allows sonic operation even in case of failures of one path or one transducer)

Can we compromise for the various effects?



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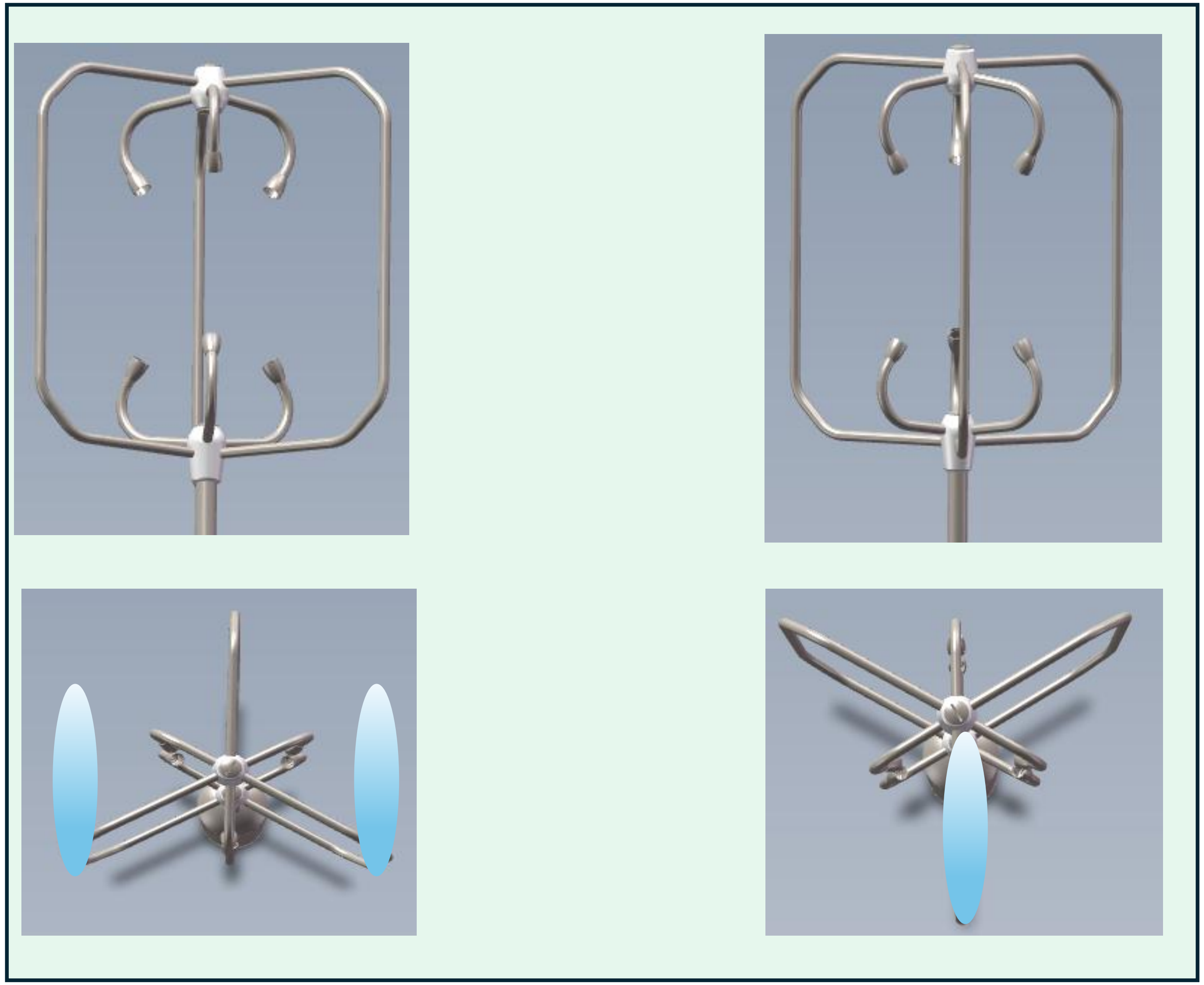
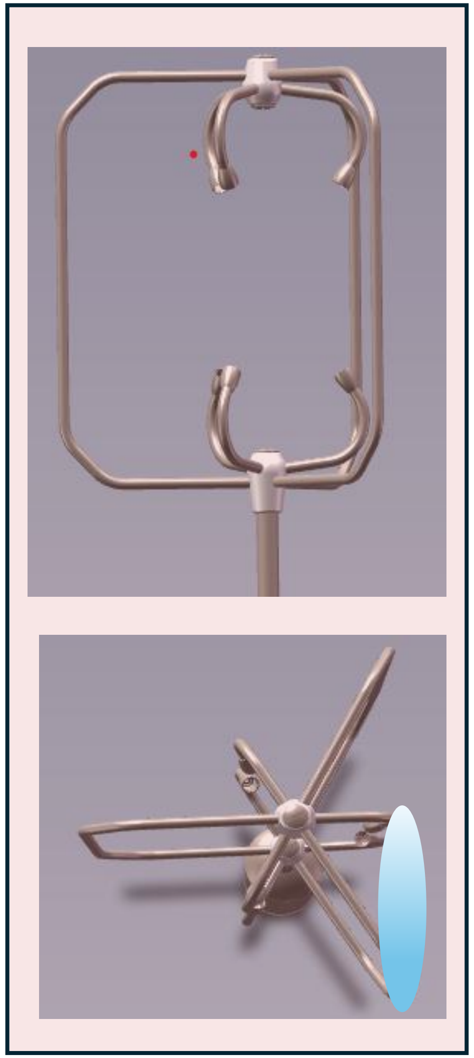
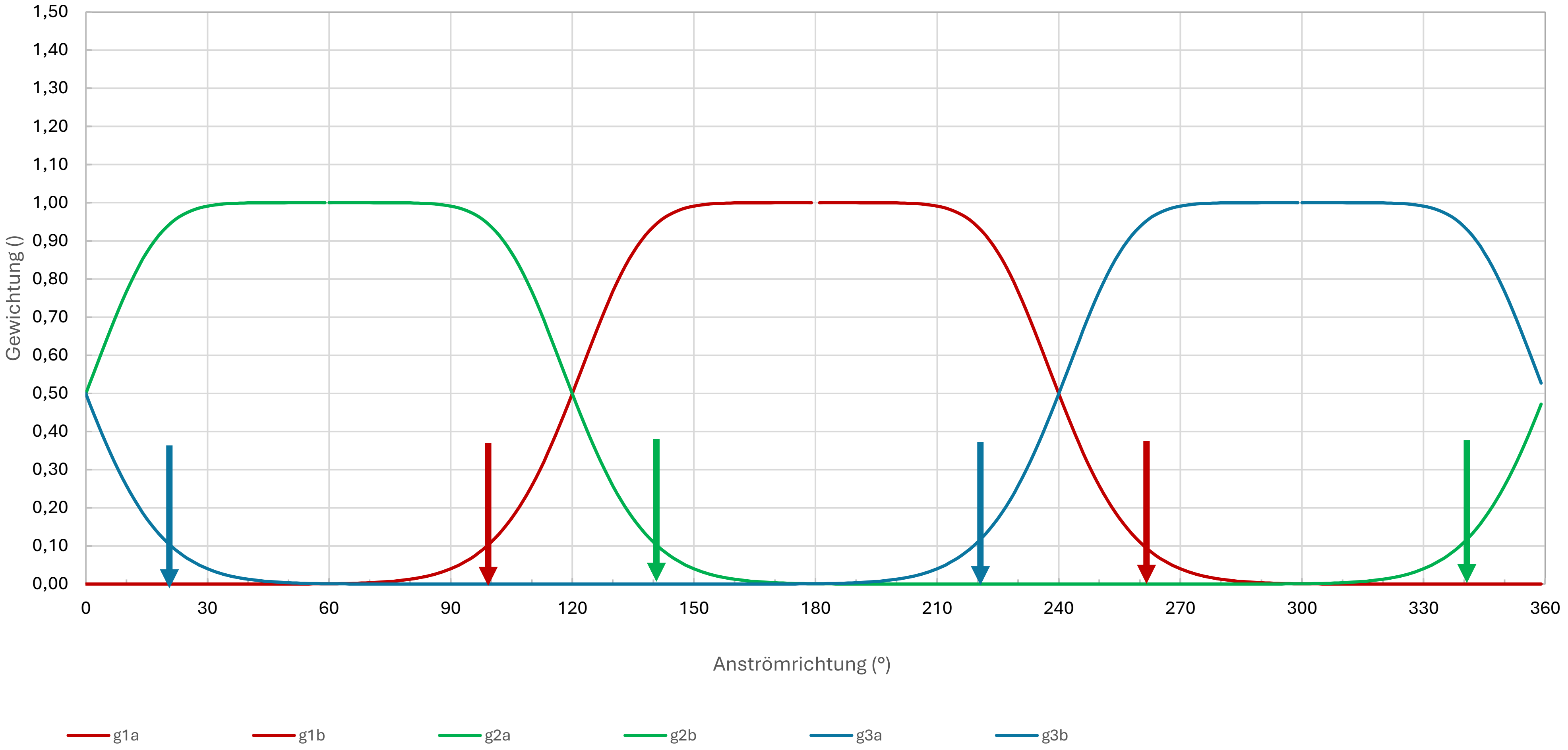
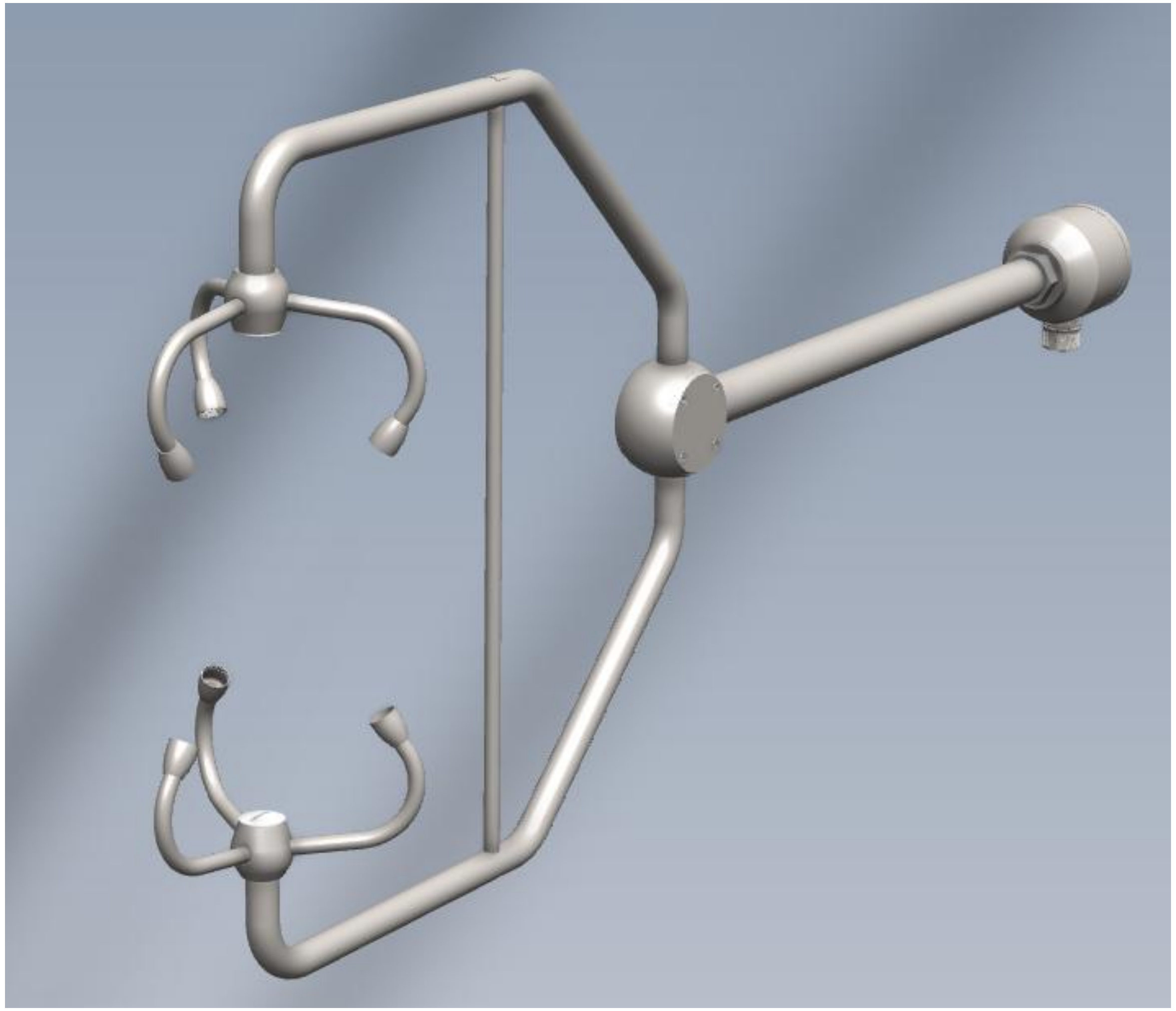




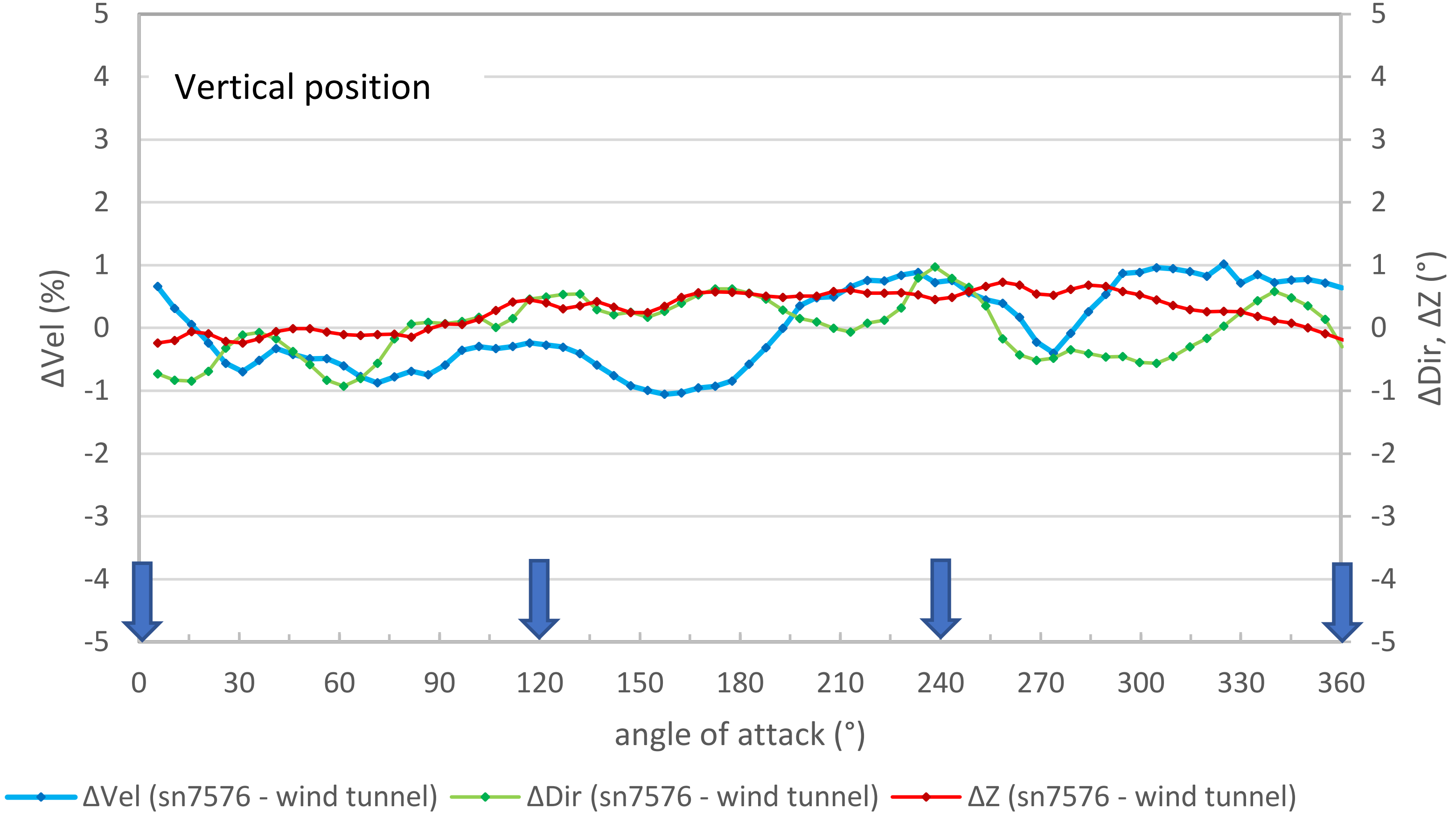
Weighting Function of Vertical Paths
Vertical bars indicate windward position relative to measuring paths



Multi-Path Sensor Heads



Wind Tunnel Test, DWG (Varel), 2020-03-19, 5 m/s
Omnidirectional Probe uSonic-3 Cage MP, SN 011202 7576



Blue arrows indicate wind ward position of outer bars

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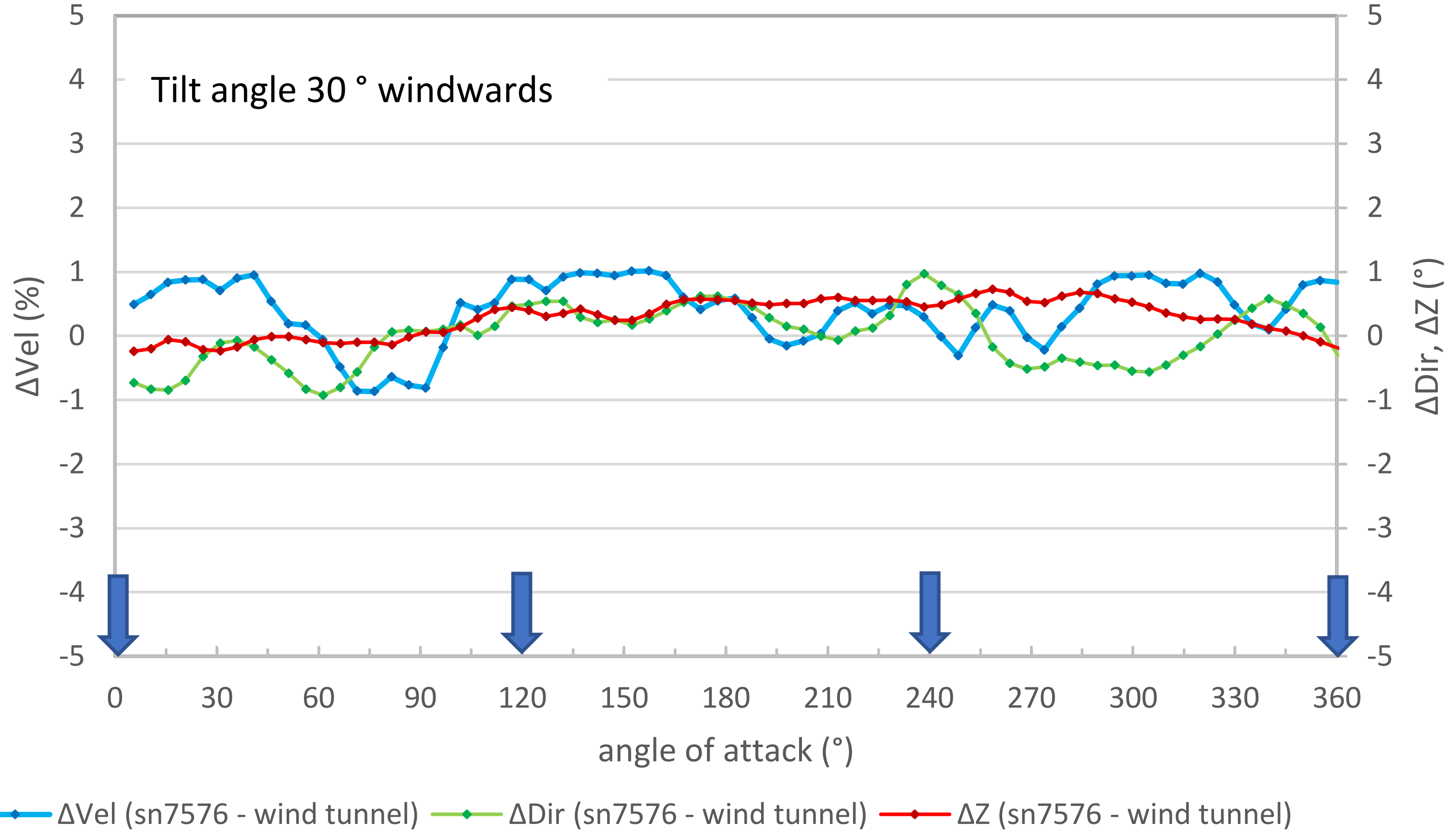

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Wind Tunnel Test, DWG (Varel), 2020-03-19, 5 m/s
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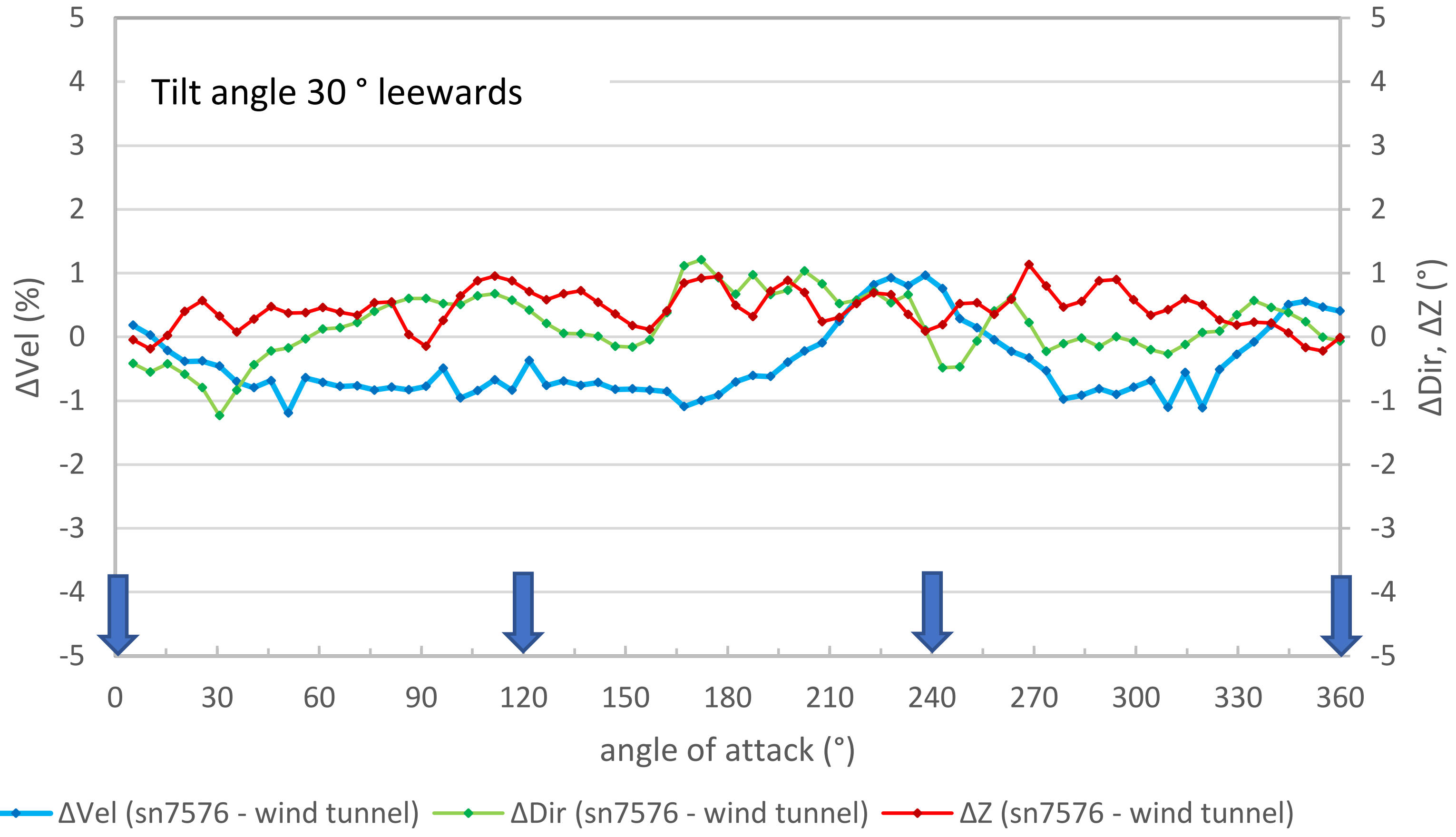

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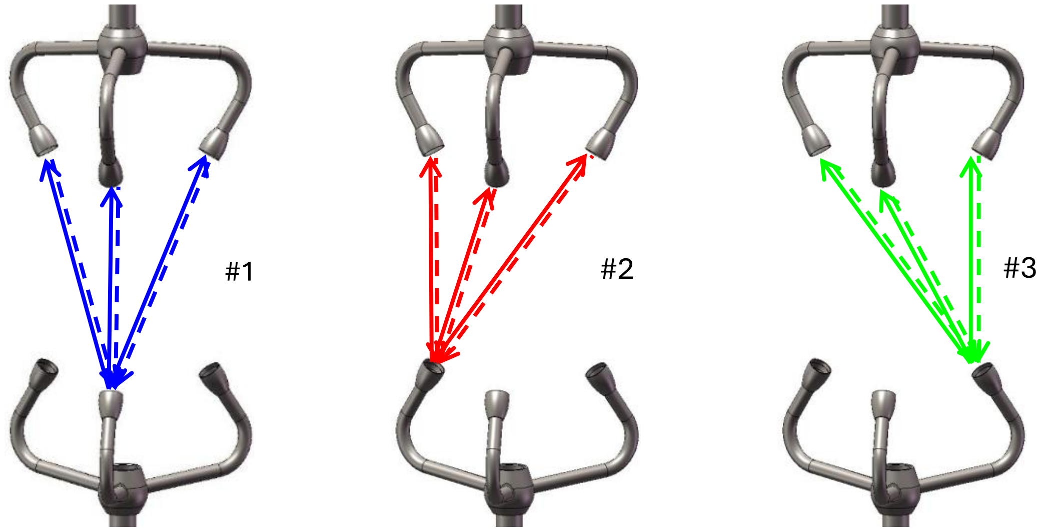

-> For the example of the heat flux

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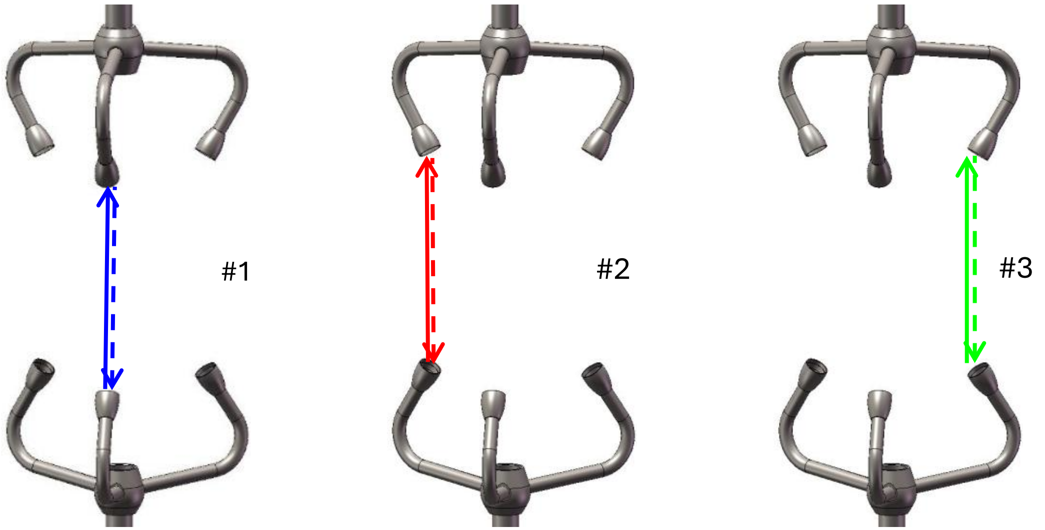

-> Derivation of heat flux from alternative combinations of vertical winds and sonic temperature

e.g. Heatflux, measured on path r12, r34 or r56

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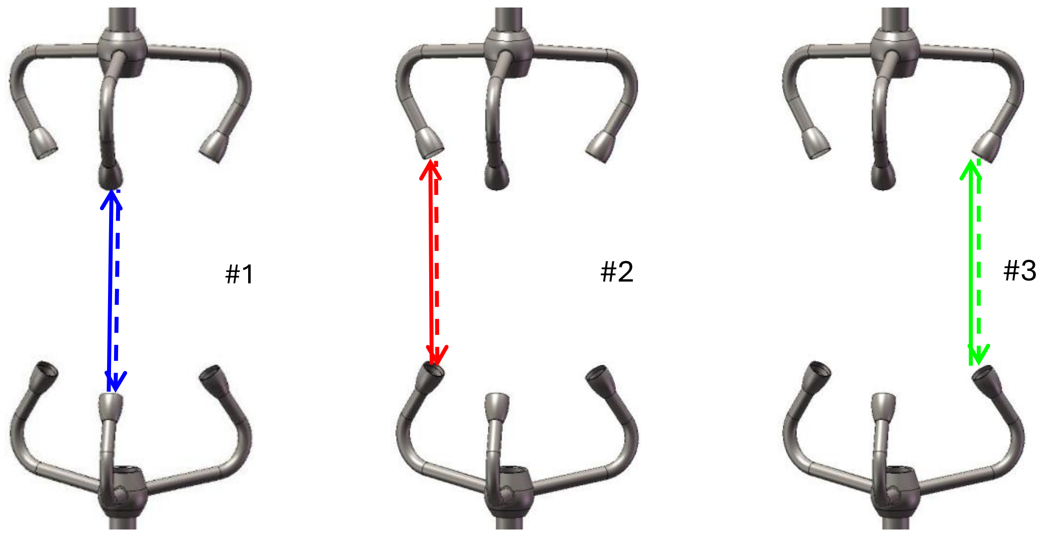

-> Derivation of heat flux from alternative combinations of vertical winds and sonic temperature

Heatflux based on (r12+r34+r56)/3 and (T12+T34+T56)/3

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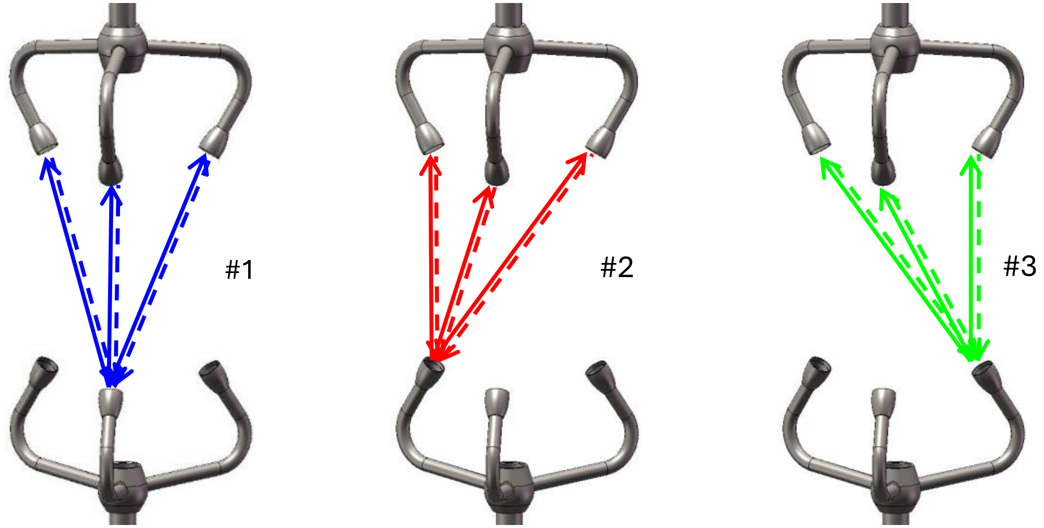

-> Derivation of heat flux from alternative combinations of vertical winds and sonic temperature

Heatflux based on z (weighting function) and T average

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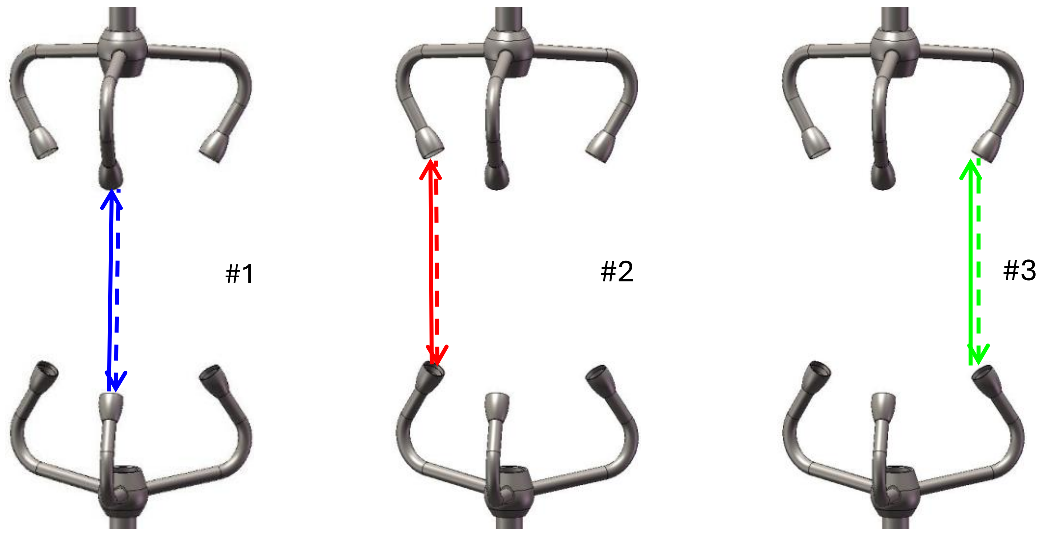
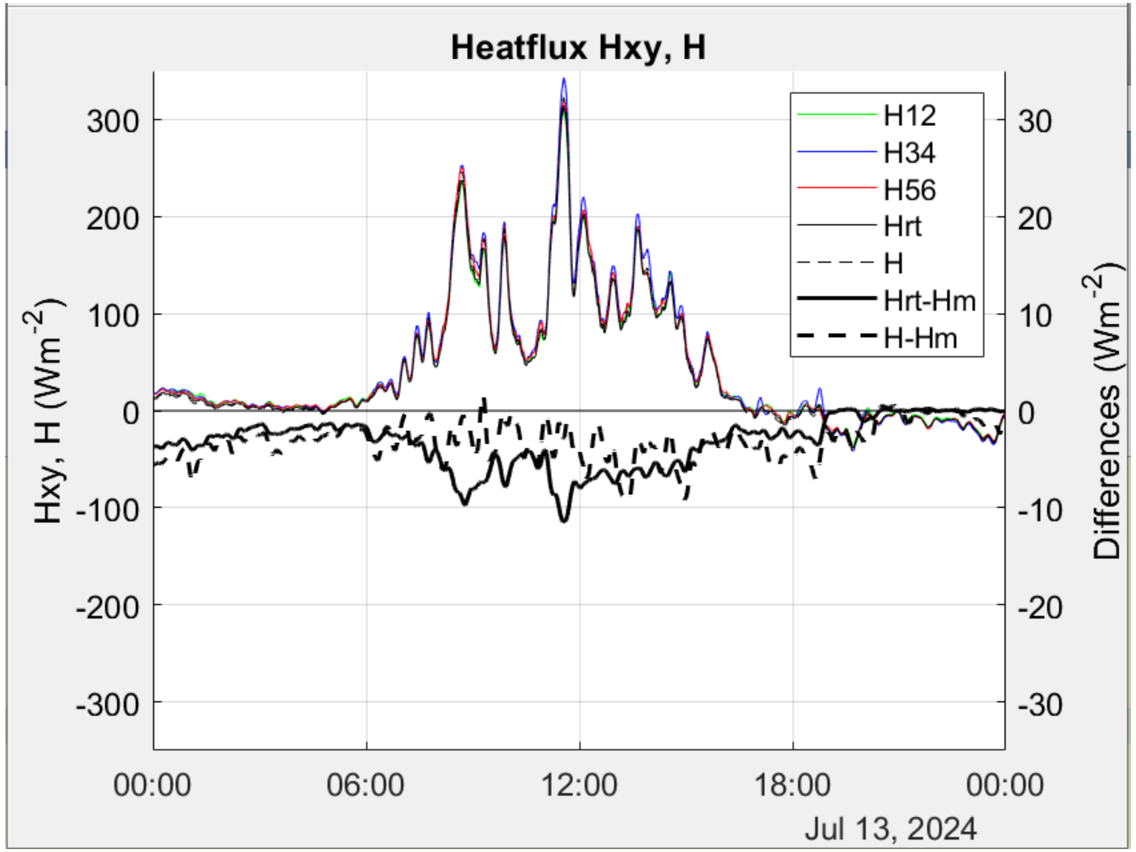


-> Derivation of heat flux from alternative combinations of vertical winds and sonic temperature

Heatflux based on (H12+H34+H56)

Derivation of heat flux from alternative combinations of vertical winds and sonic temperature



H12	Heatflux, measured on path 12
H34	Heatflux, measured on path 34
H56	Heatflux, measured on path 56
Hrt	Heatflux based on (r12+r34+r56)/3 and (T12+T34+T56)/3
H	Heatflux, based on z and T
Hm	(H12+H34+H56)/3

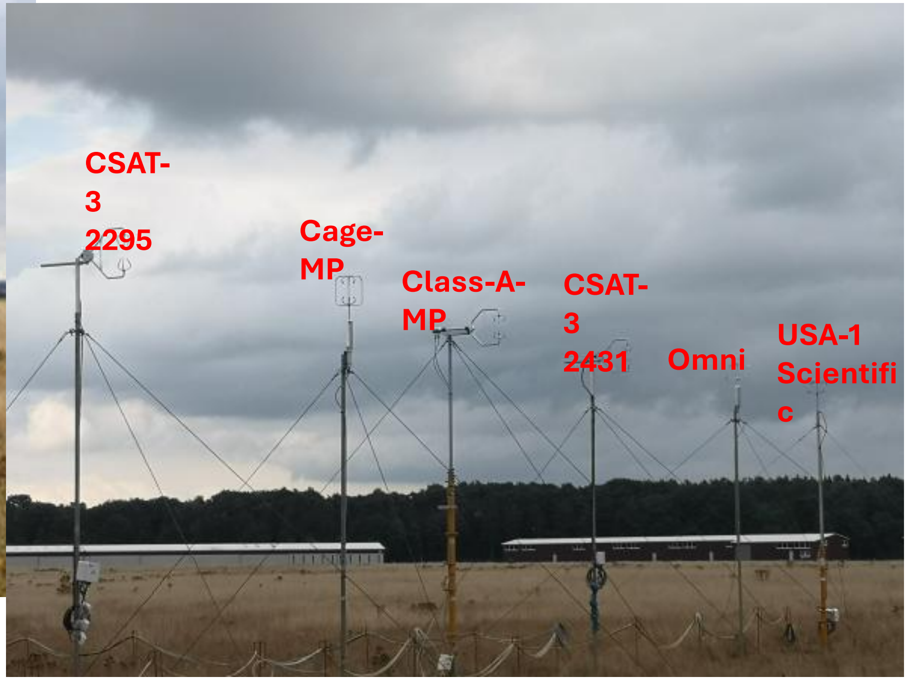
Conclusions and Outlook

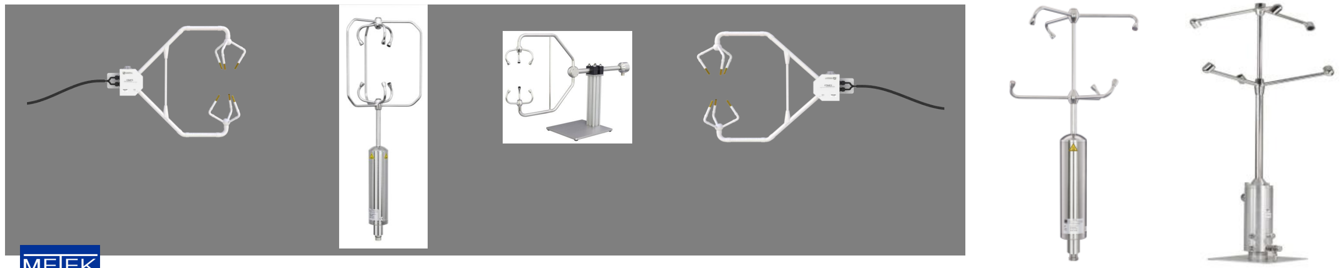
- The Multi-Path concept reduces errors from the shadow effect and flow distortion
- The 3 x 3 measurement paths provide redundancy
- Multi-Path sensor allow investigations of alternative/new algorithms involving vertical paths, tilted paths or a combination of both
- Ongoing improvements of atmospheric turbulence measurements with the Multi-Path concept as shown with the example heat flux

08.08.2022 ... 12.01.2023

Comparison of 6 sonics (2 x CSAT-3, Cage MP, Class MP, Omni, Scientific)

Height 4,2 m agl   Separation 4 m   Trailer distance 60 m





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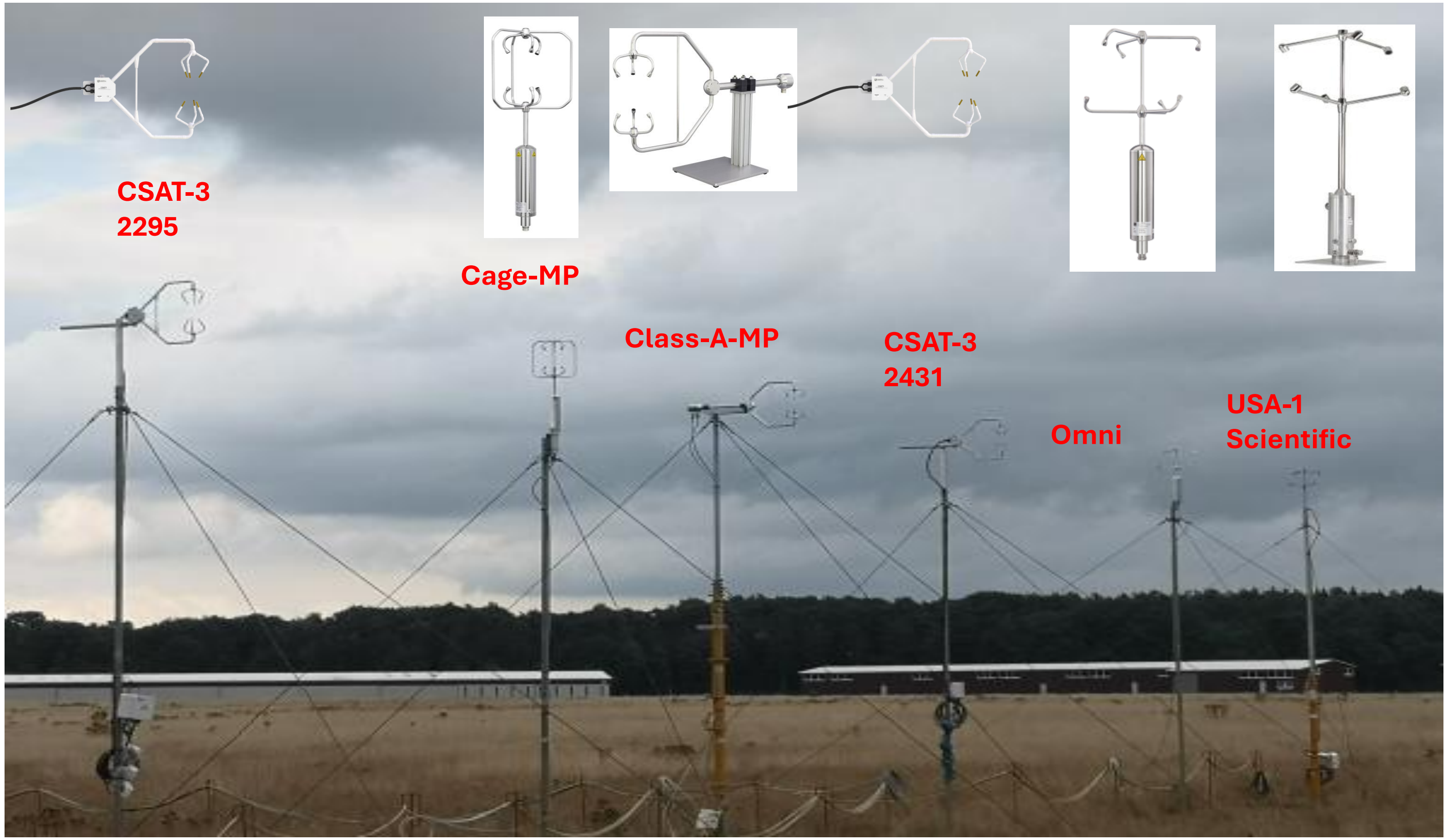
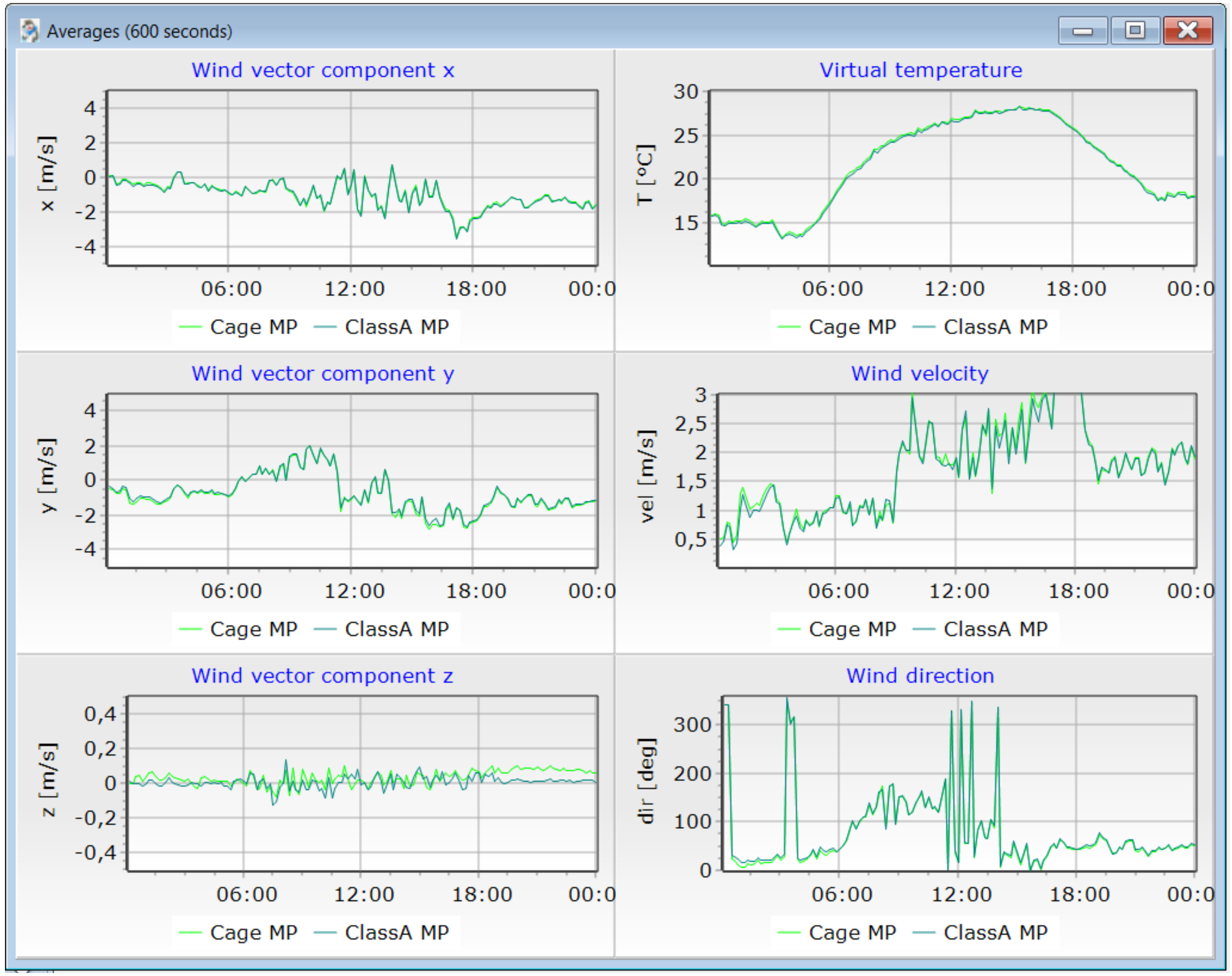
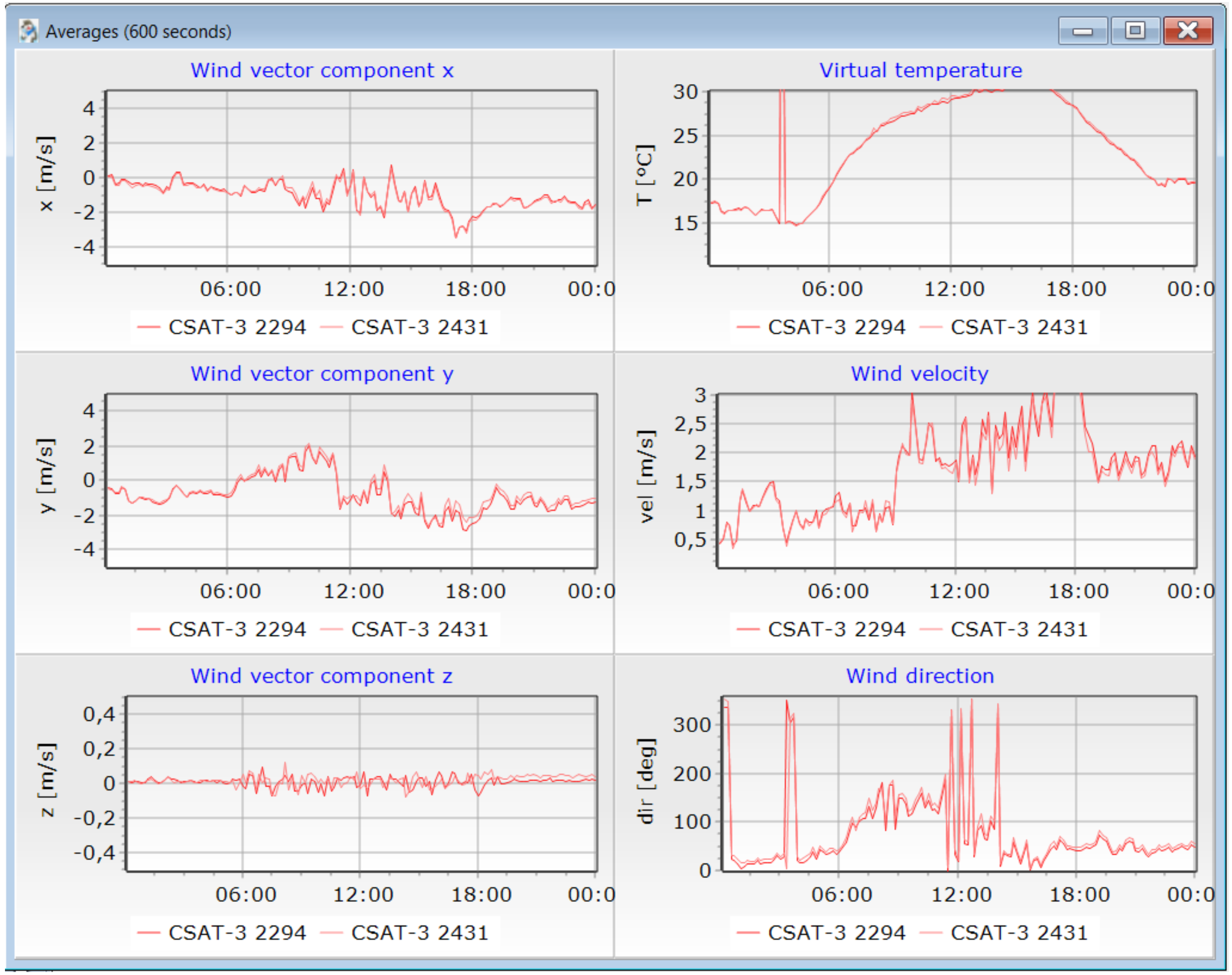
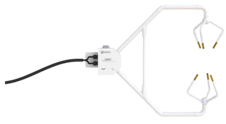
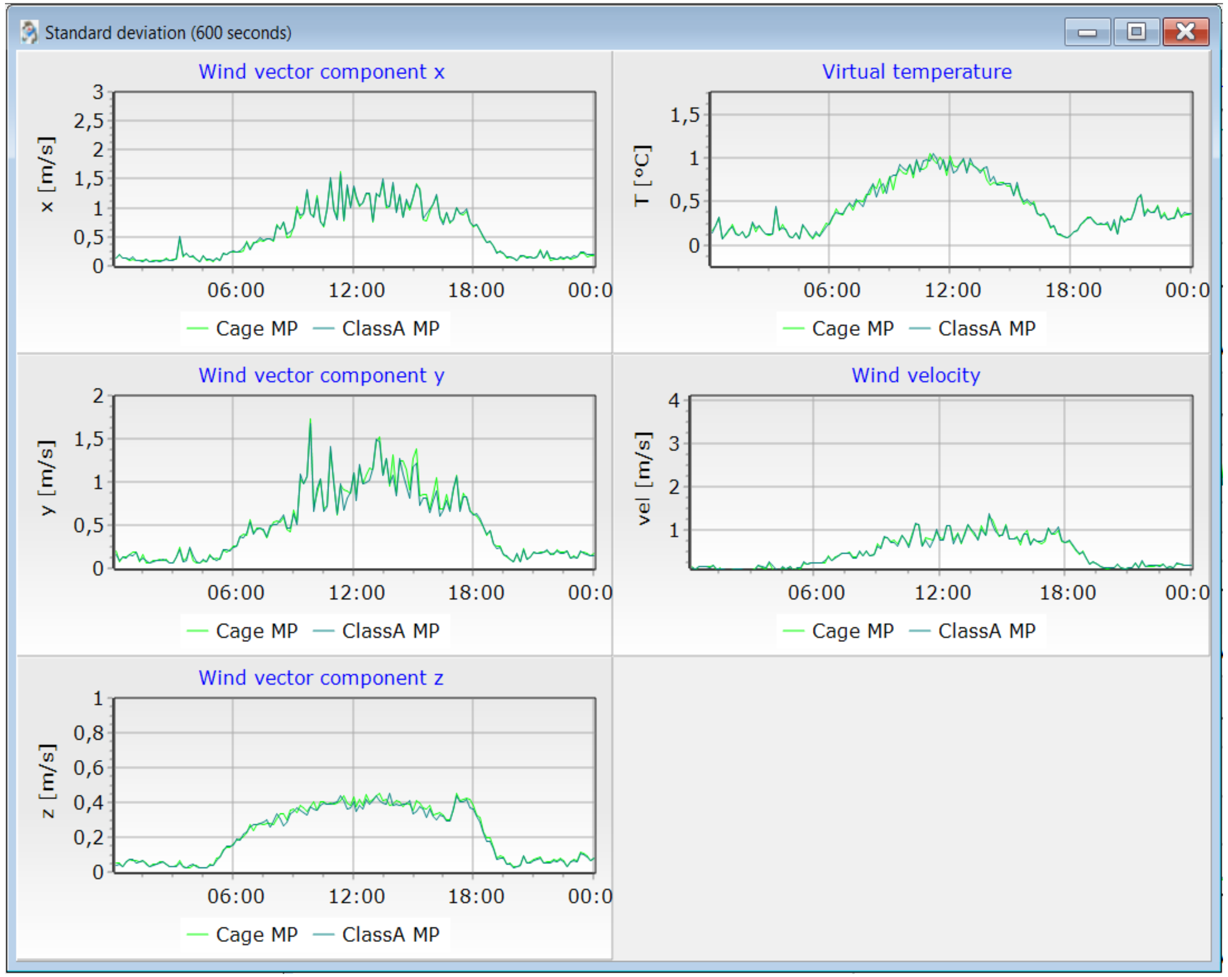


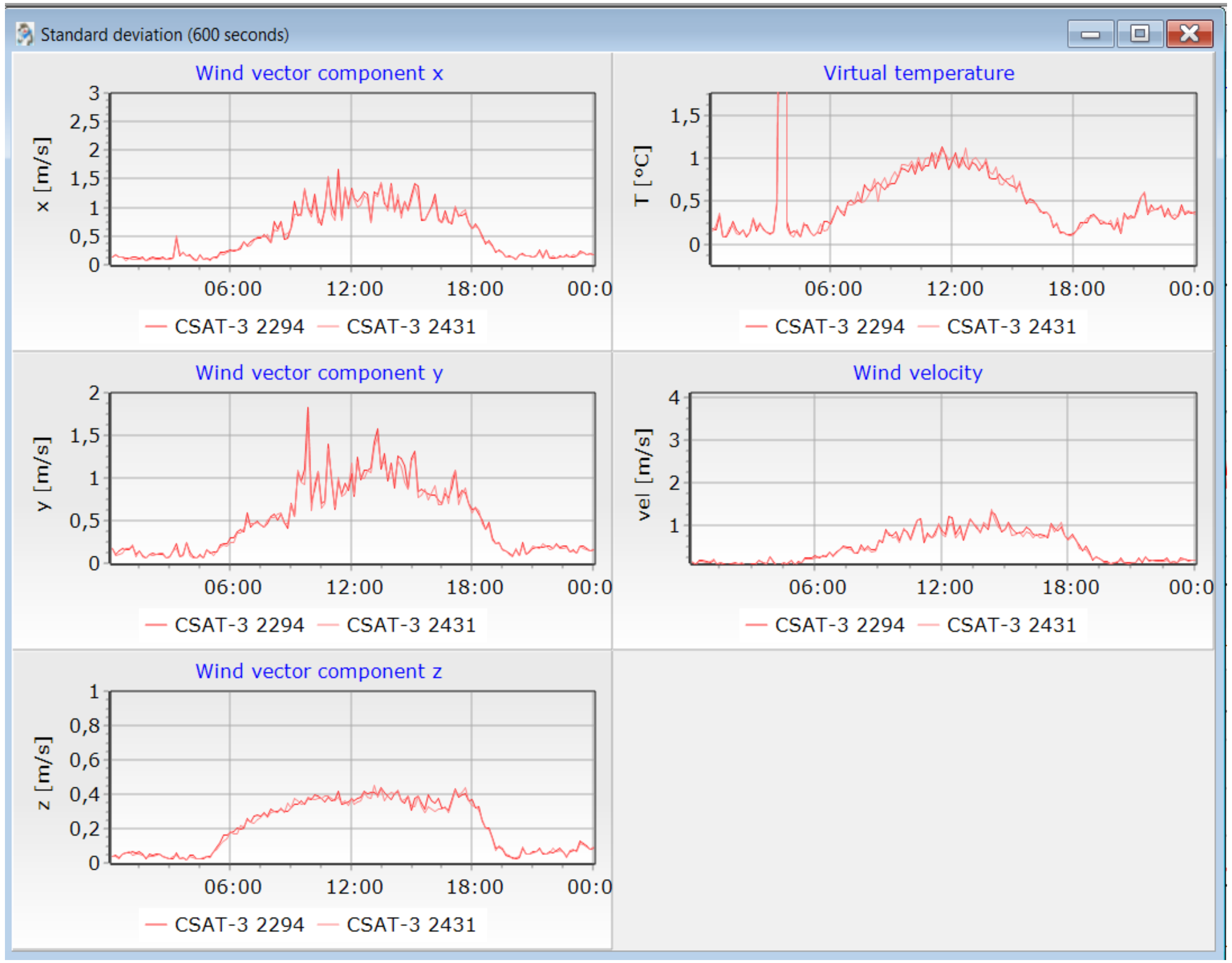




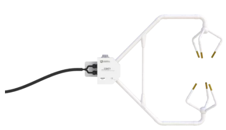
Averages, 11.08.2022, 600 s

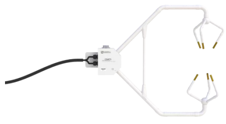






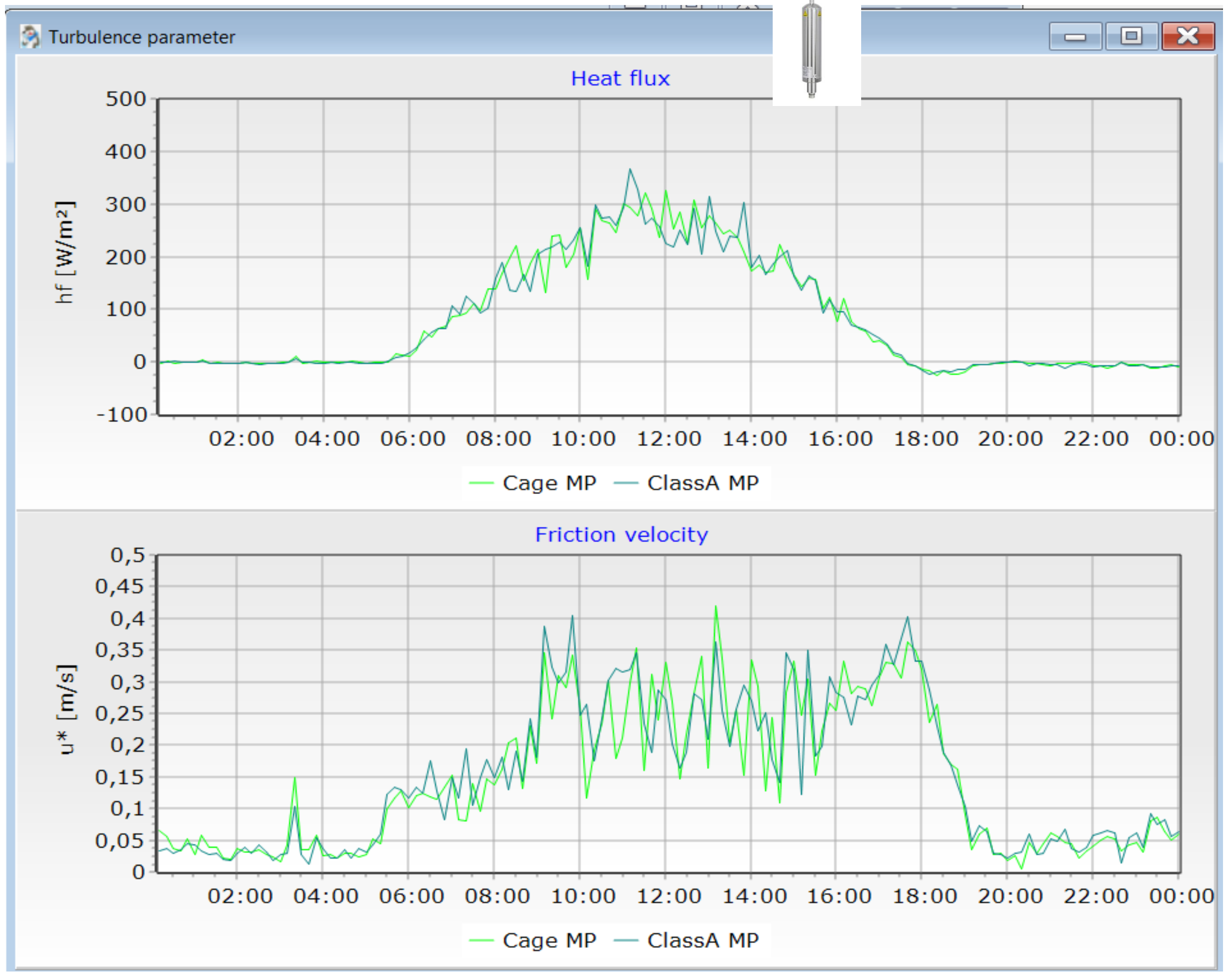
Standard Deviations, 11.08.2022, 600 s

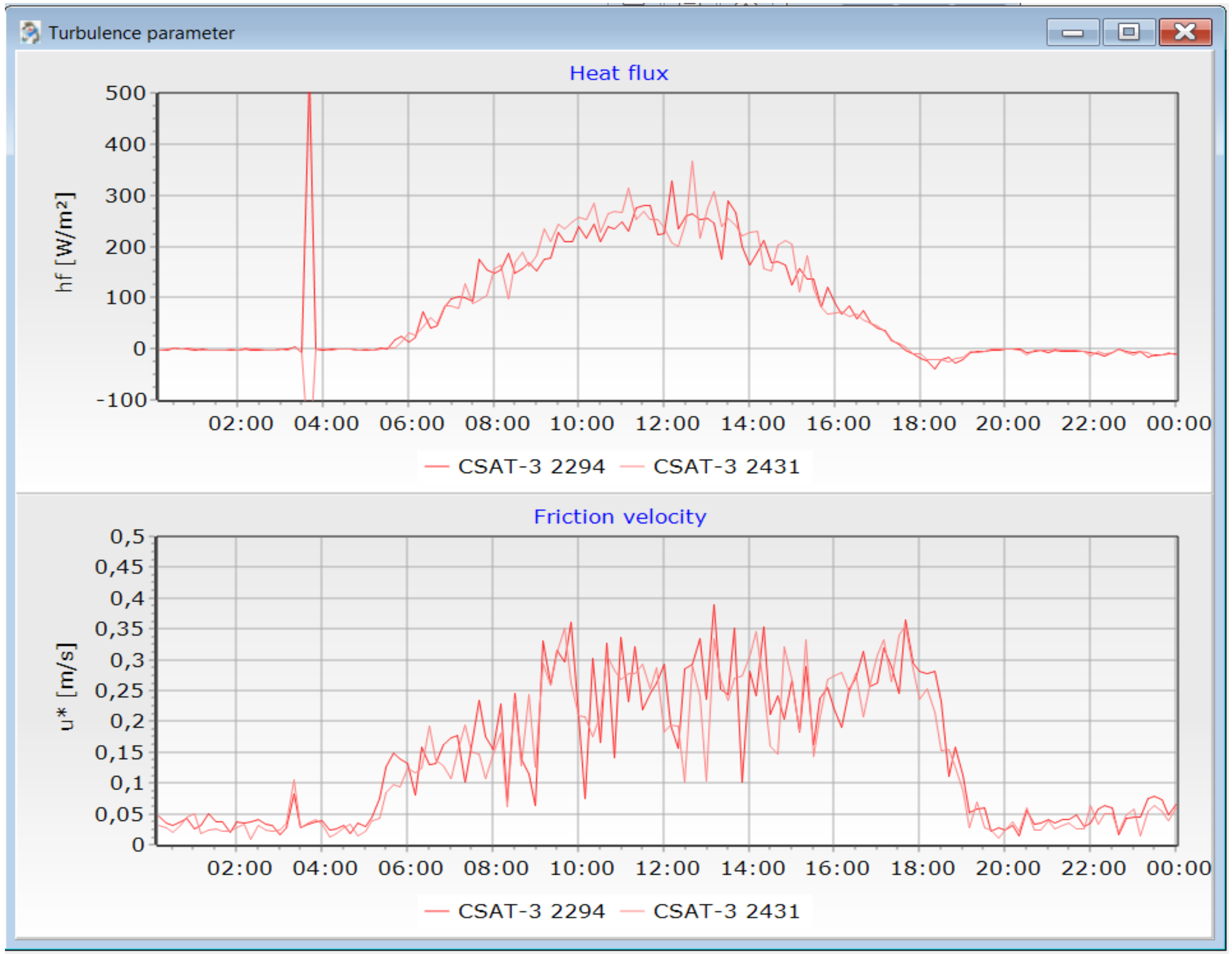




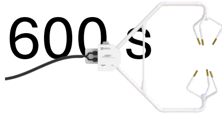


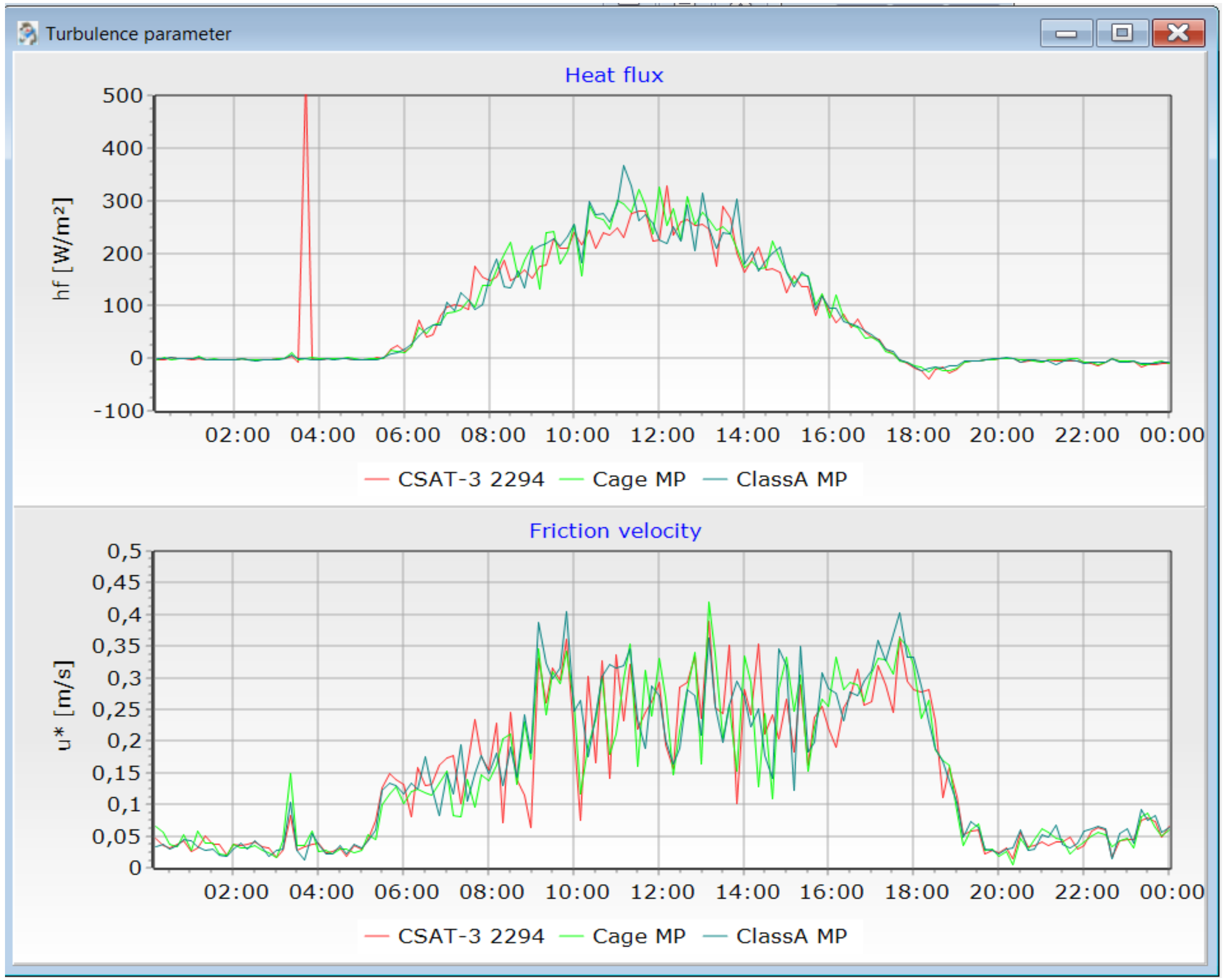







Heat Flux, Friction Velocity, 11.08.2022, 600 s



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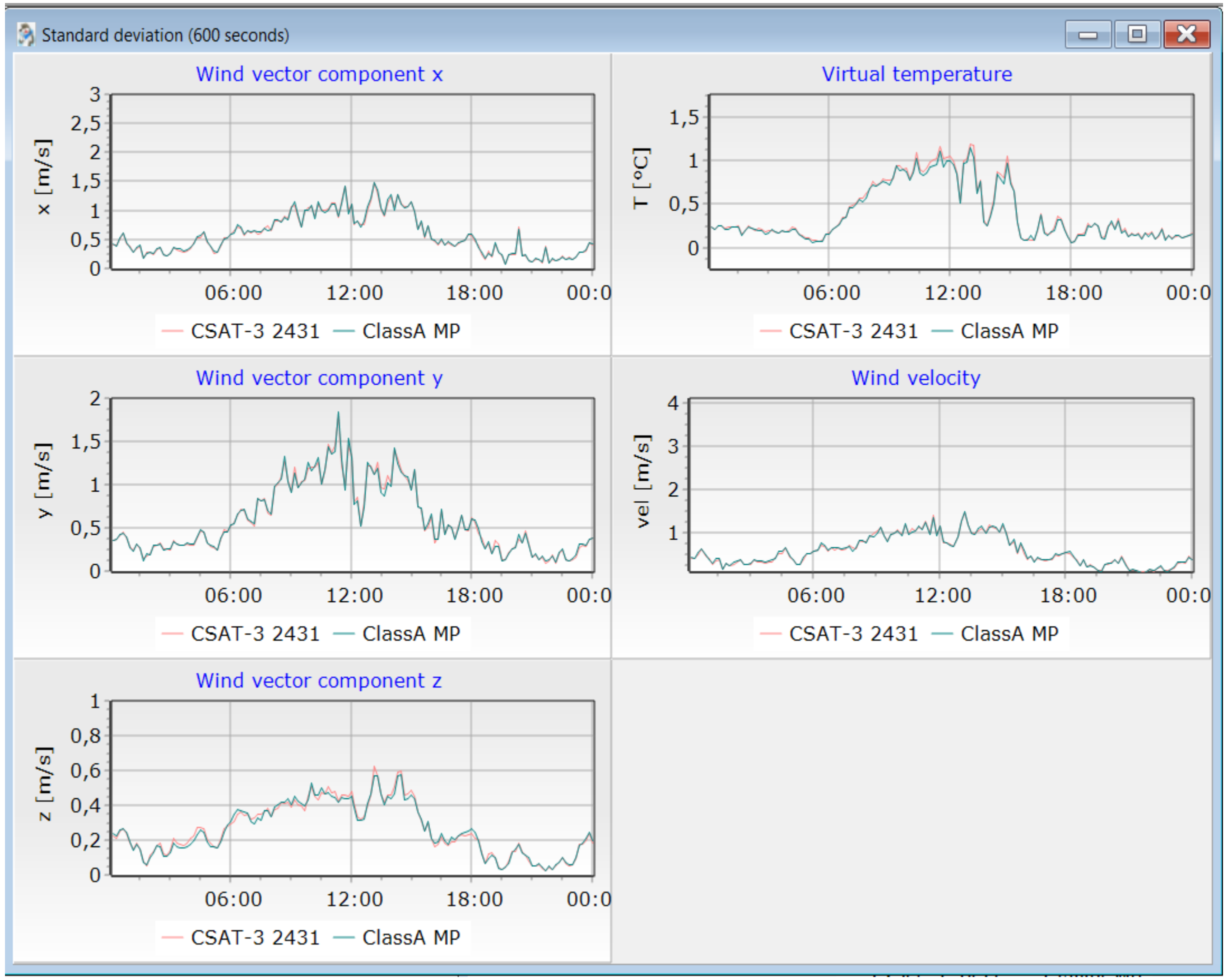
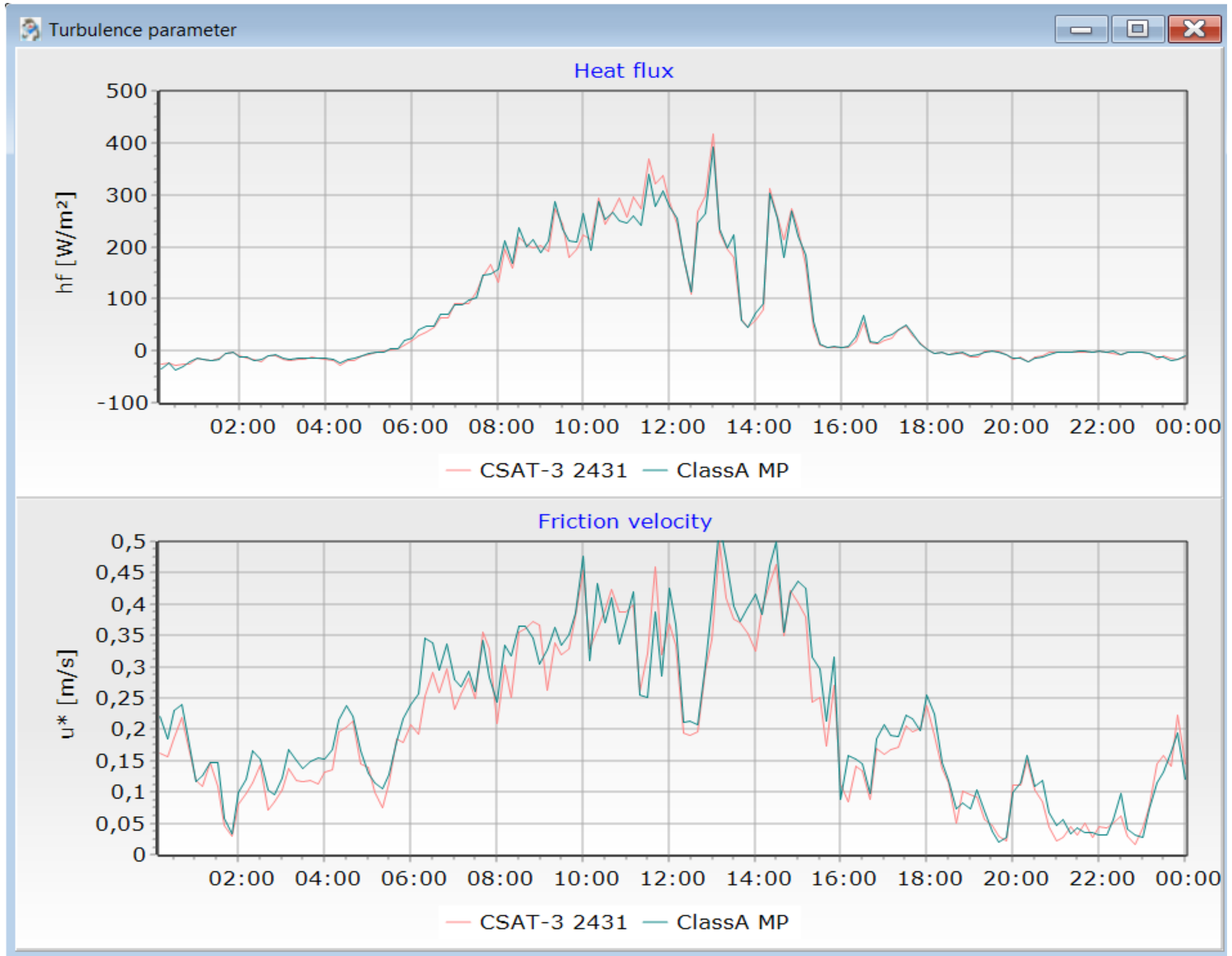
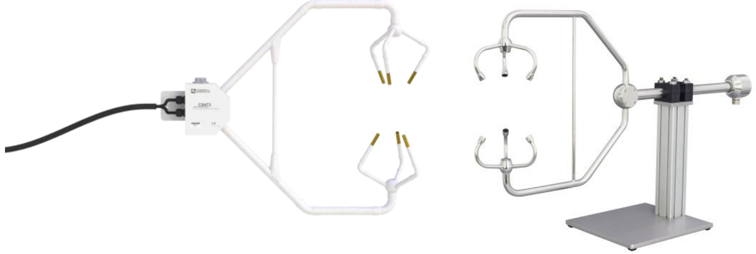
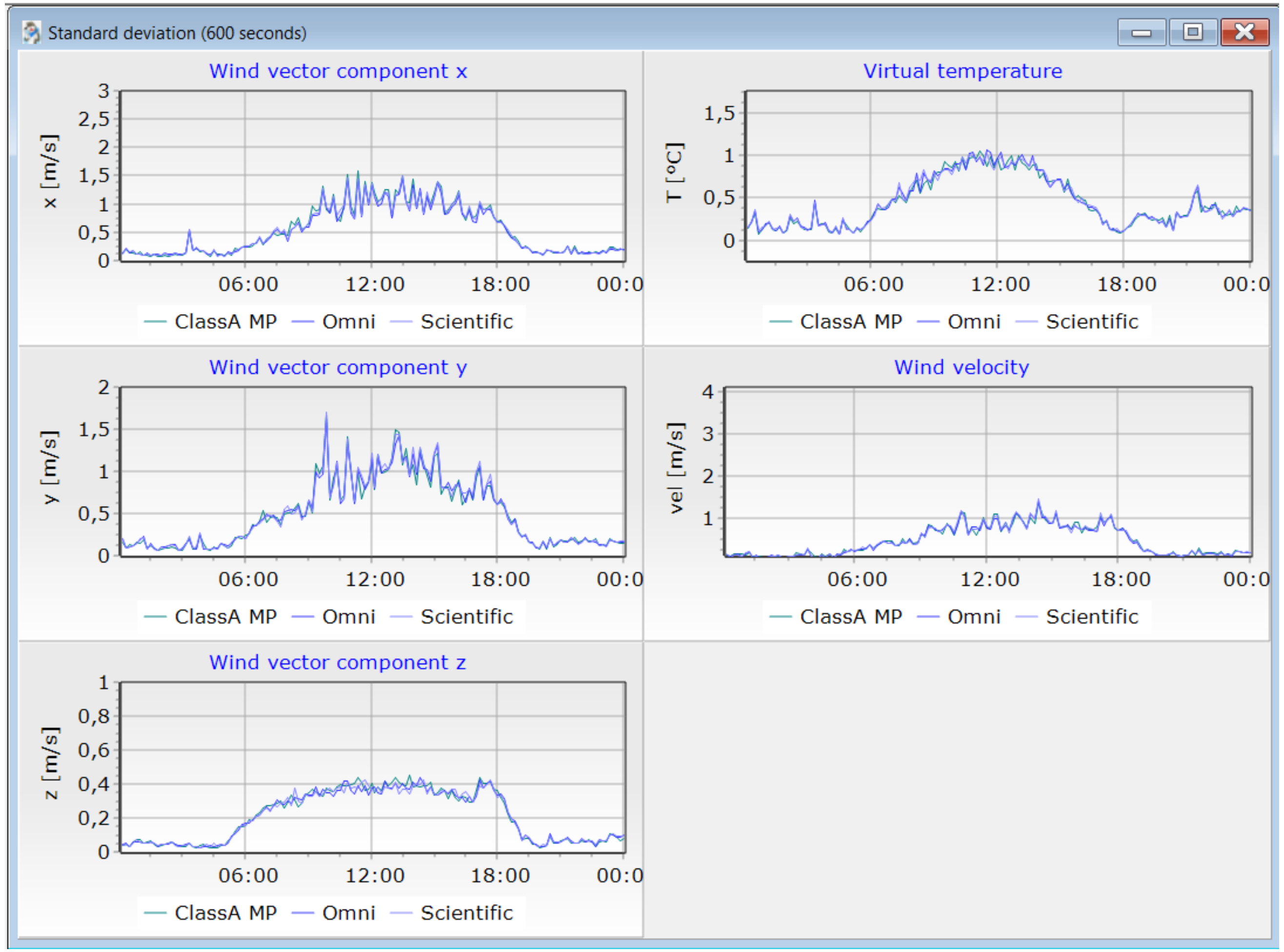
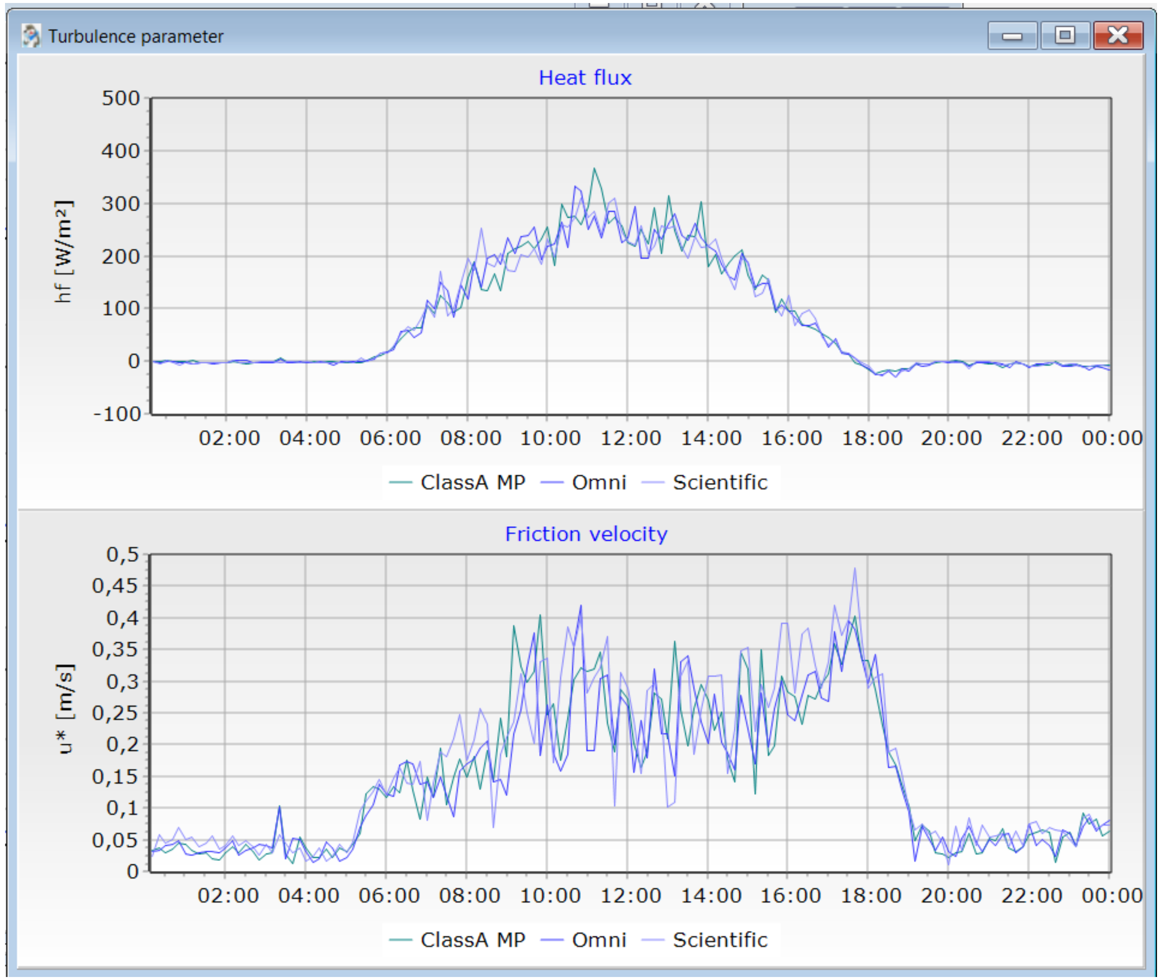




Standard Deviations, Heat Flux, Friction Velocity, 11.08.2022, 600 s







Standard Deviations, Heat Flux, Friction Velocity, 11.08.2022, 600 s