Experimental Study of Blockage Effect using Larger Ultrasonic Anemometer and Weather Station in Wind Tunnels

EURAMET project F1674 – technical protocol (February 2025)

Made by Jonas Emil Vind (jvin@dti.dk)

1. Introduction

Wind tunnel calibration of anemometers is a critical process in ensuring accurate wind speed measurements across various applications, from meteorology to wind energy assessment. However, the presence of an anemometer in a wind tunnel can significantly alter the velocity field, leading to a phenomenon known as the blockage effect. This effect, along with other factors, can introduce systematic errors in calibration results, particularly when comparing data from wind tunnels of different sizes and types.

A previous EURAMET pilot study (No. 1431) investigated the blockage effect for various types of anemometers, including vane and cup anemometers [1]. That study highlighted the complexity of wind tunnel calibrations, revealing that the blockage effect is not the only significant factor influencing calibration results. Other important factors identified, included the insertion depth effect and the positioning of reference anemometers relative to the meter under test (MUT).

In that study, a correction factor α was defined to account for the blockage effect. Denoting v_M as the velocity indication of the meter under test, $v_E(v_M)$ as the velocity indication of the reference anemometer in a wind tunnel when the meter under test indicates v_M, and $v_\infty(v_M)$ as the velocity of the asymptotically homogeneous free stream at infinity when the meter under test inserted to the stream indicates the velocity v_M, the correction factor for the blockage effect was given as:

$$\alpha(v_M) = \frac{v_\infty(v_M)}{v_E(v_M)}$$

This correction factor provides a quantitative measure of the blockage effect and allows for comparison between different wind tunnel configurations. The study also reviewed existing theories for velocity corrections, including those developed by Glauert [2] and extended by Mikkelsen and Sørensen [3], which are particularly relevant for horizontal axis wind turbines and vane anemometers.

It's important to note that the insertion depth effect, which was identified as a significant factor in the previous study, is currently being investigated in detail through EURAMET project F1565, "Insertion Depth Effect for Vane Anemometers" [4]. This ongoing research is specifically focused on understanding how the insertion depth of anemometers affects their performance in various wind tunnel configurations. While the present study (F1674) will not directly investigate the insertion depth effect, we will carefully document the insertion depths used in our experiments. This documentation will allow for potential correlations with the findings from

F1565 and contribute to a more comprehensive understanding of anemometer calibration in wind tunnels.

Building upon these collective efforts, the present study aims to extend our understanding of the blockage effect by focusing on larger ultrasonic anemometers and weather stations. These instruments are increasingly used in various applications due to their robustness and ability to measure multiple parameters simultaneously. However, their larger size is expected to exacerbate the blockage effect, potentially leading to more significant discrepancies in calibration results across different wind tunnel facilities.

This research will employ a similar methodology to the previous EURAMET project, utilizing multiple wind tunnels of varying sizes and types to calibrate selected larger ultrasonic anemometers and weather stations. By comparing the results from these diverse facilities, we aim to:

- Quantify the blockage effect for larger ultrasonic anemometers and weather stations
- Investigate the relationship between blockage ratio and the correction factor α, as defined in the previous study
- Evaluate the applicability of existing theoretical models for blockage effect correction to these larger instruments

Additionally, this study will pay particular attention to documenting the positioning of reference anemometers across participating laboratories. By carefully recording these details, we aim to better understand and potentially isolate the blockage effect from other influencing factors.

The outcomes of this study will contribute to enhancing the accuracy and comparability of wind speed calibrations across different facilities, ultimately improving the reliability of wind measurements in various applications. Furthermore, it will provide valuable insights into the specific challenges posed by larger ultrasonic anemometers and weather stations in wind tunnel calibrations, helping to establish more robust calibration procedures for these increasingly important instruments.

References:

[1] EURAMET pilot study no. 1431, "Experimental study of blockage effect in wind tunnels for calibrations of anemometers," Final report, May 2022.

[2] Glauert, H., "Airplane Propellers," Aerodynamic Theory, edited by Durand, W. F., Dover, New York, 1963, Chap. 7, Div. L, pp. 251–268.

[3] Mikkelsen, R. and Sørensen, J. N., "Modelling of Wind Tunnel Blockage," Proceedings of the 2002 Global Windpower Conference and Exhibition [CD-ROM], www.ewea.org.

[4] EURAMET project F1565, "Insertion Depth Effect for Vane Anemometers," Technical Protocol, 2022.

2. Test schedule and contact information of participants

In Table 1 below there is a timeline of the tests including the shipping address and contact person details. It is supposed that in the time period assigned for each laboratory, the laboratory performs all the measurements and sends the meters to the following laboratory which should receive the meters at the end of the period of the preceding lab. The transportation is organized and paid for by the sending laboratory.

Table 1: Time schedule and contact information

Laboratory	**Date**	**Shipping address**	**Contact**
Danish Technological Institute (DTI)	11/11/2024-29/11/2024	Teknologisk Institut, Jonas Emil Vind, Kongsvang Allé 29, 8000 Aarhus C, Danmark	Jonas Emil Vind jvin@teknologisk.dk +45 7220 2213
Lithuanian Energy Institute (LEI)	02/12/2024-03/01/2025	Lithuanian Energy Institute, Laboratory of heat equipment research and testing, Breslaujos str.3, Kaunas, LT-44403, Lithuania	Agnė Bertašienė Agne.Bertasiene@lei.lt +37037401865
Deutsche WindGuard Wind Tunnel Services GmbH (DWG)	06/01/2025-31/01/2025	Deutsche WindGuard Wind Tunnel Services GmbH, Oldenburger Str. 65, 26316 Varel, Germany	Alina Roß alina.ross@windguard.de +49(4451)9515187
Czech Metrology Institute (CMI)	03/02/2025-21/02/2025	Cesky Metrologicky Institut, Jan Gersl, Okruzni 31, 63800 Brno, Czech Republic	Jan Gersl jgersl@cmi.cz +420 602 528 299
VSL	24/02/2025-14/03/2025	VSL National Metrology Institute, Thijsseweg 11, 2629 JA Delft, Netherlands	Marcel Workamp mworkamp@vsl.nl + 31631119906
E+E Elektronik GesmbH (E+E)	17/03/2025-04/04/2025	E+E Elektronik GesmbH, ÖKD Kalibrierstelle und designiertes Labor, z.H. Dietmar Pachinger, Langwiesen 7, A-4209 Engerwitzdorf, Austria	Dietmar Pachinger dietmar.pachinger@epluse.com +43 (0)664/8245135
Federal Institute of Metrology METAS	07/04/2025-25/04/2025	Federal Institute of Metrology	Marc de Huu, marc.dehuu@metas.ch

		METAS, Laboratory for Flow, Lindenweg 50, 3084 Wabern, Switzerland	+41 58 387 0267
Physikalisch-Technische Bundesanstalt (PTB)	28/04/2025-16/05/2025	Physikalisch-Technische Bundesanstalt, Department 1.4 - Gas Flow Bundesallee 100 38116 Braunschweig Germany	Julia Hornig julia.hornig@ptb.de +49 531 592-1400
CETIAT	19/05/2025-13/06/2025	CETIAT, Laboratoire Anémométrie – Isabelle CARE, Domaine Scientifique de la Doua, 54, Boulevard Niels Bohr, 69100 VILLEURBANNE FRANCE	Isabelle Care Isabelle.care@cetiat.fr +33 (0)6 07 33 25 28
Danish Technological Institute (DTI)	16/06/2025-04/07/2025	Teknologisk Institut, Jonas Emil Vind, Kongsvang Allé 29, 8000 Aarhus C, Danmark	Jonas Emil Vind jvin@teknologisk.dk +45 7220 2213

3. The tested weather station and anemometer

The following weather station and anemometer will be used for the study:

- Weather Transmitter Vaisala WXT536
- Anemometer Thies Ultrasonic 2D

In this section we describe the basic parameters of the weather station and anemometer - including dimensions, instructions for mounting the meters to the wind tunnels, instructions for electric connections (where applicable), other settings and instructions for packing the meters for transport.

General remark:

For wind tunnels where the mounting pipes of the weather stations / meters enter the air stream (the large wind tunnels), the pipes and connections contained in the packages (or pipes and connections with the same dimensions) must be used, in order to achieve the same mounting conditions for all labs and to eliminate a possible effect of additional blockage due to e.g. a thicker pipe.

The communication configuration for the sensors should not be changed at any point. If there are problems, contact the pilot laboratory.

Packaging instructions

The weather stations / meters are transported in one package which is depicted in Figure 1.

The package contains:

- Box with the weather transmitter Vaisala WXT536
- Box with the anemometer Thies Ultrasonic 2D
- Mounting rod for Vaisala (30 mm diameter)
- Mounting rod for Thies (48.3 mm diameter)
- Vaisala connection cable
- Thies connection cable
- RS485 Unit (Expert EX9530/31)
- Power supply
- USB-A to USB-B
- USB stick with software

Ensure that all of the above is included when sending, and that the meters are packed securely so they do not get damaged when transported.

Dimensions are: 53 cm x 52 cm x 65 cm; weight: 11,2 kg

Figure 1: Packing of the meters with equipment

3.1. Weather Transmitter Vaisala WXT536

The weather station was provided by Danish Technological Institut

Basic parameters:

- Velocity range: 0 – 60 m/s
- Dimensions:
  - Height: 23.8 cm
  - Diameter: 11.4 cm
  - Width between wind transducers: 11.5 cm
- Velocity indication: Reading using software
- Resolution: 0.1 m/s
- Serial number: R0410365

Figure 2: Vaisala WXT536, right picture showcasing bottom where the cable is connected

The tip of the weather stations transducers has some red coloring on them from earlier project but they have no impact on the measuring.

Mounting in a wind tunnel:

The weather station can be connected to a mounting rod which can be fixed to a construction outside the wind stream. The weather station is installed at approximately wind direction 0 °, where 0 ° is north pointing towards the wind direction. The general wind direction can be seen at the bottom of the weather station, denoted with an arrow. The final alignment should be done using the weather station's readout at a wind speed of 10 m/s.

The included cable is connected to the 8-pin M12 connector at the bottom of the weather station for data sampling. The other end of the cable is connected to a computer with the data software installed.

Cable setup:

Included with the weather station is a Vaisala USB cable (link). This both supplies power as well as making it possible to read the data from the weather station.

Figure 3: Vaisala communication cable

Packing for transport:

The weather transmitter Vaisala WXT536 is transported in a box with Styrofoam protection around it, this can be seen on Figure 4.

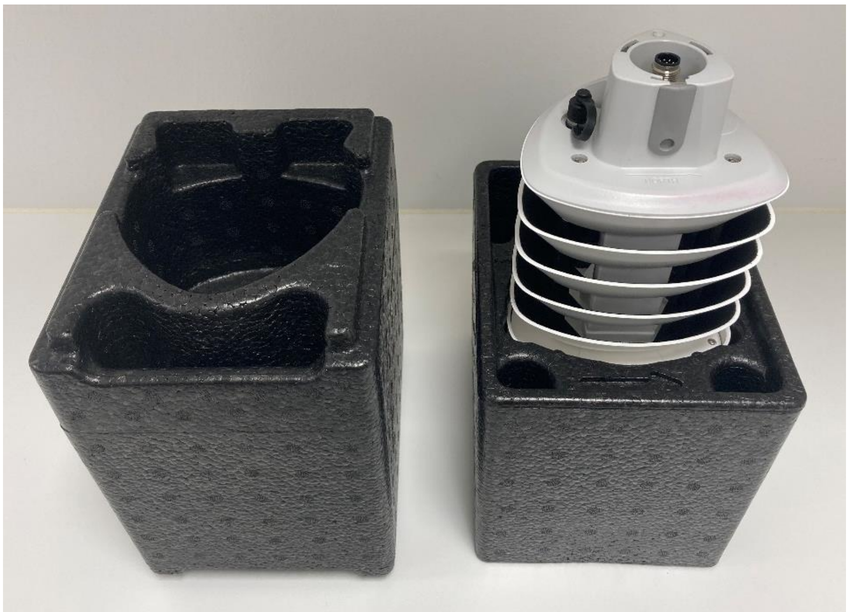

Figure 4: protection box for Vaisala WXT536

The Styrofoam protection is already slightly broken and some of Styrofoam might break off when handled.

3.2. Anemometer Thies Ultrasonic 2D

The anemometer was provided by Deutsche WindGuard.

Basic parameters:

- Type: 4.3820.01.300
- Velocity range: 0 – 85 m/s
- Dimensions:
  - Height: 42,4 cm
  - Diameter: 28.7 cm
  - Width between transducers: 20 cm
- Velocity indication: Reading using software
- Resolution: 0.01 m/s
- Serial number: 01230038

Figure 5: Thies Ultrasonic 2D

Mounting in a wind tunnel:

The ultrasonic anemometer can be connected to the appropriate mounting rod which can be fixed to a construction outside the wind stream. The anemometer is installed approximately at wind direction 0 °, where 0 ° is north pointing towards the wind direction. The red mark on one transducer indicates north. The final alignment should be done using the anemometers readout at a wind speed of 10 m/s.

A cable is connected to the bottom of the anemometer for data sampling. The other end the cable is connected to a RS485 unit and power supply. From the RS485 unit a USB-cable is connected to the computer with the data software installed.

Cable setup:

Included with the Thies Ultrasonic 2D is a connection cable as well as power supply, an RS485 unit and a USB-A to USB-B cable.

Figure 6: On the left the Thies cable and the RS485 unit. On the right the power supply

Packing for transport:

The anemometer Thies Ultrasonic is transported in a box with Styrofoam protection around it, this can be seen on Figure 7.

Figure 7: Protection box for Thies Ultrasonic 2D

4. Overview of the participating wind tunnels

In Table 2, seen below, is a list of the participating wind tunnels ordered by size.

Table 2: Overview of the participating wind tunnels

Lab	Wind tunnel type	Meas. section type	Nozzle shape	Nozzle diameter/width
		Open measuring section or box		
E+E	closed	open	circular	25.5 cm
PTB	closed	open	square	50 cm
VSL	closed	open	circular	38 cm
LEI	closed	box	circular	40 cm
CMI	closed	open	circular	45 cm
DWG	closed	Semi-closed	square	100 cm
		Closed measuring section		
CETIAT	closed	closed	square	50 cm
METAS	closed	closed	rectangle	74 cm x 49 cm
DTI	open	closed	square	50 cm

5. Measurement procedure

The meters should be temperature stabilized to the laboratory temperature for at least three hours before the start of the measurement.

If possible, the ambient conditions should be kept in the following ranges:

- Temperature: 21 (± 3) °C
- Relative humidity: 30 – 70 %
- Barometric pressure: Near atmospheric

The meters should be calibrated according to the standard procedure of each lab. The calibration points are given in Table 3. Where each speed is done for each degree. The calibration velocities are the velocities indicated by the meter under test (not by the reference), i.e. the velocity in a wind tunnel should be set in a way that the meter under test indicates values as near as possible to the values prescribed for every angle which can be seen in Table 3. The prescribed angles are also according to the indication of the meter. If a laboratory has a setup for noting the correct angle, then this can be noted down but is not mandatory.

For each angle the meter under test should be set at 10 m/s as the angular precision becomes better with higher speeds. When the angle is set, the different calibration points are taken. The velocities should be set starting from the lowest one and increasing to the highest one in order to avoid any unwanted effects. Then the meter is rotated to a new angle and checked at 10 m/s before starting over with the calibration points.

The position of the meter under test should be set so the ultra-sonic sensors are in the middle of the test section or just above. If this is not possible, please note it. The position regarding to the outlet position then the equipment should be placed in the core region which for most open measuring section is approximately 1 diameter from the inlet.

For every measurement point taken the laboratories' own method of taking measurements should be used, however it should be done after achieving stability using multiple measurements over minimum 30 seconds and noting the average for the readings to ensure sufficient quality.

A picture of the setup, as well as approximated distance from the meter to the outer walls, must be noted.

Table 3: Calibration points

Anemometer	Calibration points (m/s)	Angle (degrees)
Weather Transmitter Vaisala WXT536	1 / 2 / 3 / 4 / 5 / 6 / 8 / 10 / 12 / 14	0 / 30 / 60 /90 / 120 /
Anemometer Thies Ultrasonic 2D	1 / 2 / 3 / 4 / 5 / 6 / 8 / 10 / 12 / 14	0 / 30 / 60 / 90

6. Data supplied to the pilot laboratory

The following data should be provided to the pilot laboratory (DTI) by email to (jvin@teknologisk.dk) no later than one month after finishing the measurements.

Measurement error data

- indication of the meter under test (MUT) in m/s (average from multiple repetitions)
- indication of the reference (average from multiple repetitions)
- corrections applied to the indication of MUT or the reference (e.g. a correction for the blockage effect (if applied); a correction of a velocity difference in position of the MUT and the reference (if applied); ...)
- error of the MUT as calculated by the procedure of the particular laboratory

Uncertainty data

- uncertainty budget – list of all considered uncertainty components and their values, especially uncertainty related to the blockage effect - if applied (see the section 7 below)
- the total combined expanded (k = 2) uncertainty of the meter error

Ambient conditions

- temperature
- barometric pressure
- humidity

Geometry data

- geometry of the measuring section (shape, dimensions, walls, ...)
- position of the meter under test (regards to the inlet, outlet, walls, floor and roof)
- position of the reference (regards to the inlet, outlet, walls, floor and roof)
- parameters of the reference (type, size (if not LDA))

Please use the supplied excel document to structure the data as it makes data comparison easier later. It can be found on the supplied USB stick or if needed being sent from the pilot laboratory.

7. List of the principal components of the uncertainty budget

- type A uncertainties of the meter under test (MUT) and the reference
- resolution of the MUT and the reference
- uncertainty of the calibration factor or error of the reference
- uncertainty due to the blockage effect (if applied)
- uncertainty of the correction of a velocity difference in position of the MUT and the reference
- uncertainty due to non-homogeneity of the velocity field in the area occupied by the MUT
- uncertainties related to the installation angles of the MUT and the reference

8. Principle of evaluation of the results

The factor α as defined in the introduction will be estimated experimentally including its uncertainty with the value of $v_\infty(v_M)$ given by the reference velocity value of the largest wind tunnel in the project (Deutsche WindGuard) where the blockage effect can be considered as almost negligible.

The factor $\alpha(v_M)$ will be determined for all wind tunnels and all anemometers in the project and the velocities v_M given in Table 3. Trends in the dependencies of α on the blockage ratio and on the velocity v_M will be investigated.

Appendix A – Communication with the devices

This section describes how to communicate with the two devices. Both devices are set up to output periodic data allowing a simple consol logging setup, as well as their respective software.

Software can be found on the USB stick included in the packaging. Here are also included drivers in case any is missing. If there is any trouble with the connection, please notify the pilot laboratory so a solution can be found and might be included in this report.

Weather Transmitter Vaisala WXT536 – Communication parameters

- Baud rate: 19200
- Data: 8
- Parity: none
- Stop bits: 1

Anemometer Thies Ultrasonic 2D - Communication parameters

- Baud rate: 19200
- Data: 8
- Parity: none
- Stop bits: 1

Using "PComm" to showcase output

Both the Vaisala and Thies equipment can use this software. Just set up the connection with the correct settings from above and choose the right COM-port.

On Figure 8 the output form of Anemometer Thies Ultrasonic 2D can be seen. The first data is the speed in m/s and the second is the degree angle of the wind direction.

On Figure 9 the output from Vaisala WXT536 can be seen. Here the data which start with "Dm=" is the speed in m/s and "Sm=" denotes the degree angle of the wind direction.

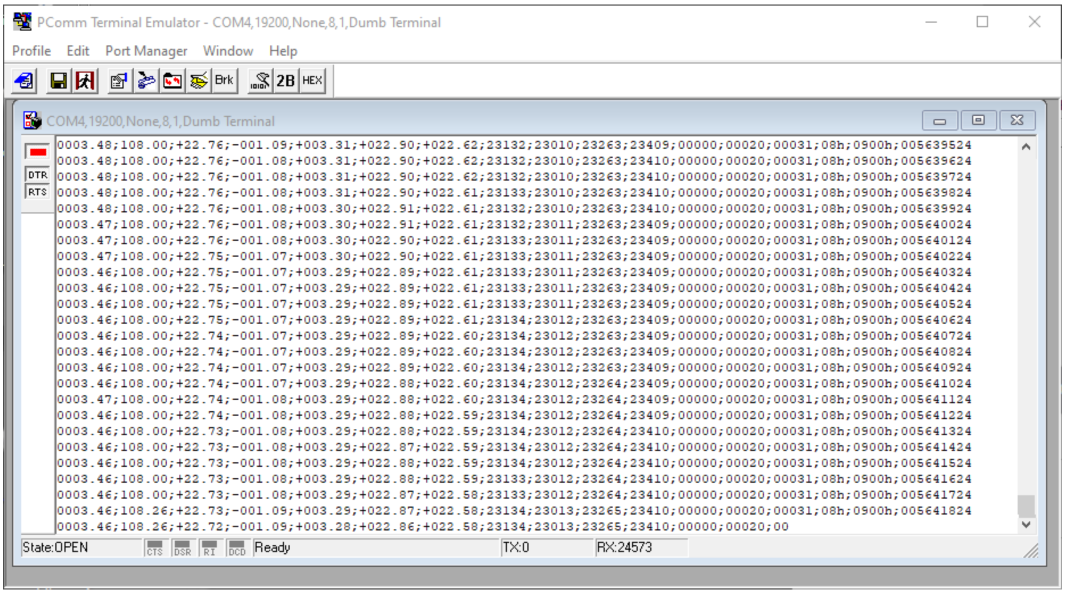

Figure 8: Output from Anemometer Thies Ultrasonic 2D

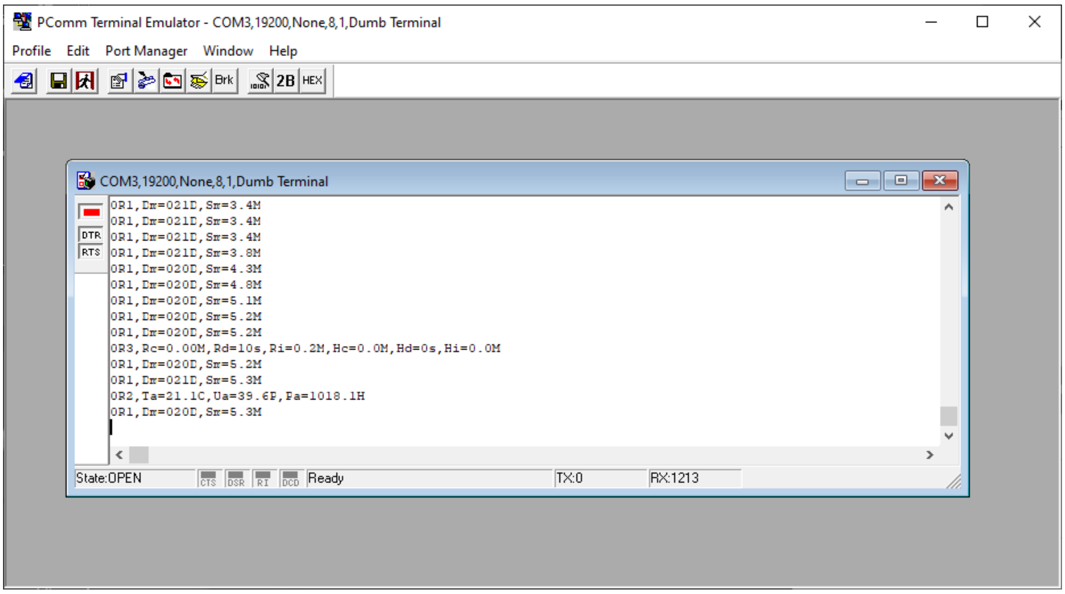

Figure 9: Output from Vaisala WXT536

Using Vaisala Configuration Tool

An option for the Vaisala WXT536 is to use the included configuration tool which displays the data in a nice way. See Figure 10.

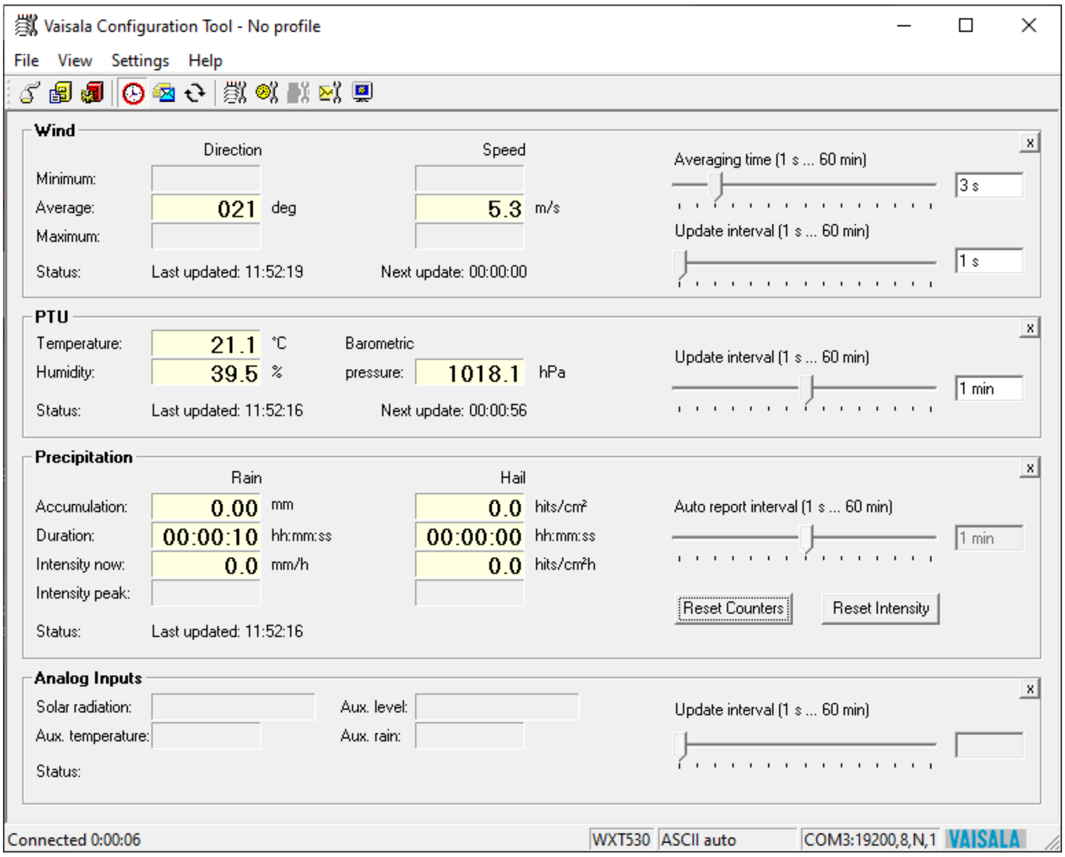

Figure 10: Vaisala Configuration Tool

Using Thies Device Utility

An option for the Anemometer Thies Ultrasonic 2D is to use the included utility tool which also helps in displaying the data. See Figure 11. However sometimes it seems to have a hard time finding the device.

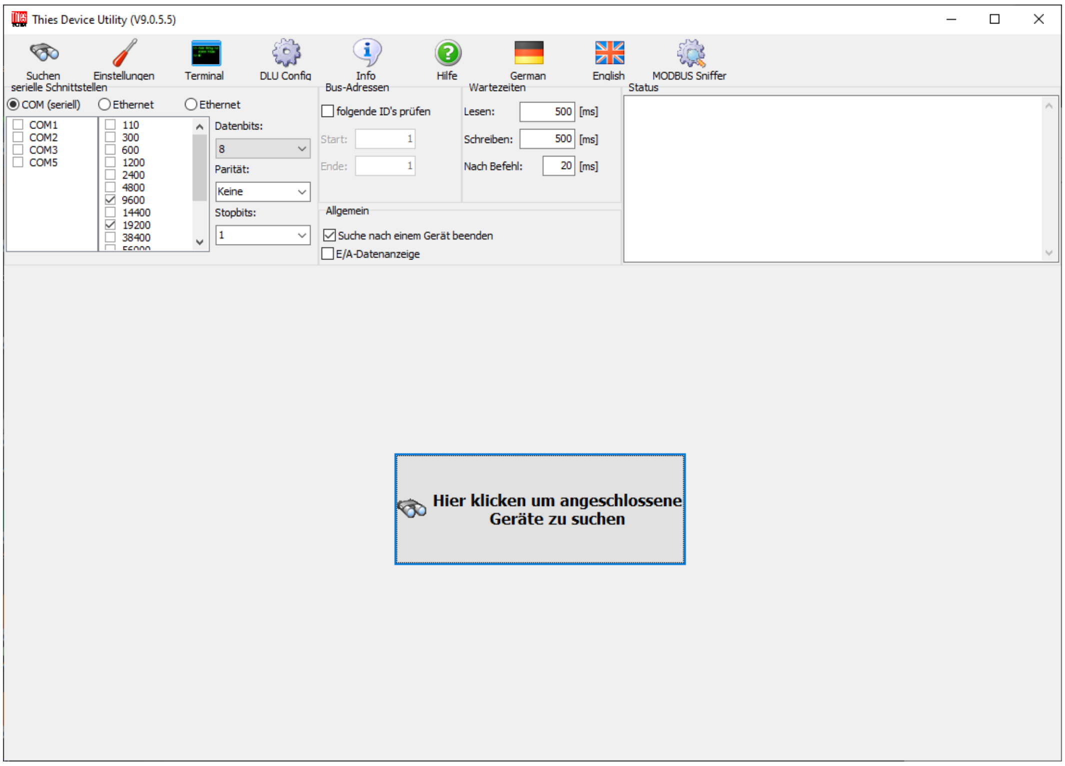

Figure 11: Thies Device Utility