OPERATIONAL TEST OF SONIC WIND SENSORS AT KNMI

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ABSTRACT

The Royal Netherlands Meteorological Institute (KNMI) conducted a laboratory en field test of three commercial 2D sonic wind sensors in 2003. Based on the results of these tests and recent instrument developments, KNMI decided to replace its cup anemometers and wind vanes by 2D sonic wind sensors on account of cost reduction. As a first step of this implementation of sonic wind sensors in the operational meteorological network, a batch of 10 sonics has been purchased and will be subjected to wind tunnel tests and a 1 year field test at 10 locations. The locations cover different conditions that are encountered in the Netherlands, i.e. production platform on the North Sea, coastal station, inland station with and without high (variations in) surface roughness, airport, and 200m meteorological mast at Cabauw. During the field test the sonics will be operated in parallel to the operational cup anemometers and wind vanes. The evaluation of the field test results will address various aspects that are of interest for meteorological and climatological users. These aspects include e.g. the construction of transfer functions for wind direction, - speed and - gust that account for the change from one sensor to another under various conditions, the sensitivity to aircraft induced vortices at airports and changes that are required to the currently used anti-vortex filter, the suitability of sonics for wind profile measurements etc. The data availability, stability and maintainability of the sonic wind sensors will also be verified during the field test. Furthermore, the usefulness of the sonic temperature measurements will be investigated. The results presented in this presentation concern the wind tunnel and climate chamber tests.

1. INTRODUCTION

The Royal Netherlands Meteorological Institute (KNMI) uses conventional cup anemometers and wind vanes to measure wind speed and direction. Although the KNMI cup and vane meet WMO requirements concerning the accuracy of wind measurements (WMO 1996), the sensors require a relatively large amount of maintenance and occasionally some anemometer freeze during winter conditions. Therefore, the usage of alternative wind sensors has been considered. In a previous study three commercial 2D sonic wind sensors have been tested (Wauben, 2005 and Wauben, 2007). Based on the results of these tests and recent instrument developments, KNMI decided to replace its cup anemometers and wind vanes by 2D sonic wind sensors on account of cost reduction. The Thies 2D was selected by KNMI (Thies, 2008). This sensor is an advanced model compared to the Thies 2D sensor considered in the previous test. The advanced sensor has an extended measurement range up to 75m/s and an improved housing of the transducers which prevents any damage by birds. With these improvements the shortcomings of the previous test have been solved.

KNMI, however, decided that the Thies 2D is not suitable for wind profile measurements in the 200m meteorological mast at Cabauw. The reason for this is the following. The transducers/arms of the 2D sonic sensor disturb the wind field and affect the measurements when the wind is parallel to a transducer pair. For horizontal wind this disturbance is taken into account by a wind direction and - speed dependent correction that is applied in the sensor software. This correction is less adequate for non-horizontal winds. Errors of up to -8% occur when the wind is parallel to a transducer pair with an inclination angle of about 10° (Wauben, 2007). Such a wind direction dependent error is unacceptable for the wind profile measurements where a wind speed accuracy of maximally 2% for all wind directions is required. Hence KNMI also conducts a test with 2 3D sonic wind sensors in order to evaluate their suitability for wind profile measurements. The Thies 3D and Gill Windmaster Pro have been selected for this purpose. Both sensors are commercially attractive and furthermore these sensors have the same mounting and connector as the Thies 2D and the Gill R3-100, respectively. The Gill R3-100 is already used by KNMI for turbulence measurements at Cabauw.

2. LABORATORY TESTS

Wind tunnel tests will be performed in the Low Speed Tunnel (LST) of the Dutch National Aerospace Laboratory (NLR) that is operated by DNW (German-Dutch Wind Tunnels) and in the TNO (Netherlands Organisation for Applied Scientific Research) wind tunnel. The LST wind tunnel test will be used for the verification of the calibration of the horizontal wind whereas the TNO wind tunnel will be used for tests with inclined sonic wind sensors. The Thies 2D, Thies 3D, Gill Windmaster Pro and the KNMI cup anemometer will be tested. These wind tunnel tests will be performed in September and October 2008.

KNMI also operates its own wind tunnel which is of the so-called Eiffel type with a closed measurement section (cf. Figure 1). The space available for calibration in this measurement section has a length of 0.4m and a diameter of 0.4m. The wind speed range is 0.2m/s to about 27m/s. Details of the KNMI wind tunnel can be found in Monna (1983). A Lambrecht 1405 vane anemometer is used as the reference for measuring the tunnel wind speed in the KNMI wind tunnel. This anemometer is regularly calibrated outdoors together with a KNMI cup anemometer. The absolute calibration of both sensors is determined and from that the calibration factor to be used for a cup anemometer in the KNMI wind tunnel is determined. The accuracy of the wind speed calibration of the KNMI cup anemometers in the KNMI wind tunnel over the wind speed range is estimated to be ±2%±0.1m/s (Monna, 1987). The wind tunnel has been equipped with a azimuth table on which a sensor can be mounted and rotated around 360° in azimuth with an accuracy better than 0.1º A set of tools is available to mount the KNMI cup anemometer, Thies 2D, Thies 3D, Gill Windmaster Pro and Gill R3-100 in a fixed orientation. Using this setup the wind speed and direction measurements of the sonics can be tested.

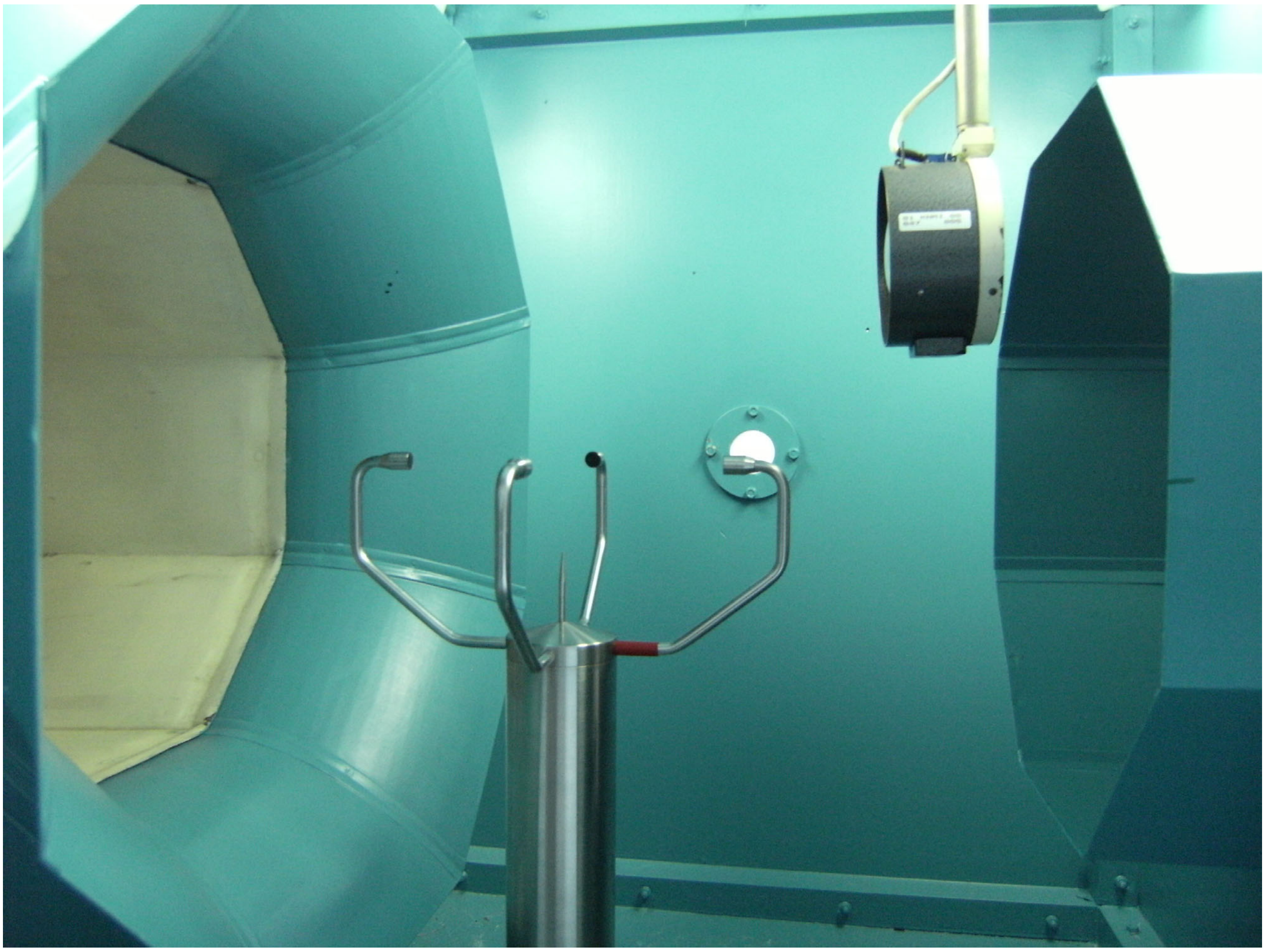

Figure 1: A Thies 2D sonic wind sensor in the measurement section of the KNMI wind tunnel.

All 10 Thies 2D ultrasonic wind sensors have been tested in the KNMI wind tunnel. Each sensor was placed in the wind tunnel mounted on the azimuth table and rotated over 360° in steps of 2°. At each azimuth angle 5 1-second averaged sensor readings were obtained. The averaged (and standard deviation) of the sensor wind direction have been compared with angle of the azimuth table and the wind speed is compared with the tunnel reference speed. At this moment the blocking factor of the KNMI cup anemometer is used. The wind tunnel measurements have been performed at the tunnel reference speeds of 1, 2, 3, 5, 7, 10, 15 and 20m/s. In addition some tests at 0m/s has been performed as well as tests with an azimuth angle step of 1°. The 0m/s test showed no indication of disturbances by reflections. The sensor always reported a wind direction of 0° and the wind speed was at most 0.05m/s. Figure 2 shows an example of a 1° azimuth scan of 2D Thies SN 0408010 in the KNMI wind tunnel. The reference wind speed is 5.21m/s and the variation is below ±0.05m/s. The wind speed and direction reported by the sonic have an offset of 0.12m/s and 0.9°, respectively. The wind speed clearly shows the disturbance of the wind field caused by the transducers. Both the speed and direction show the 90° symmetry that could be expected for the sensor.

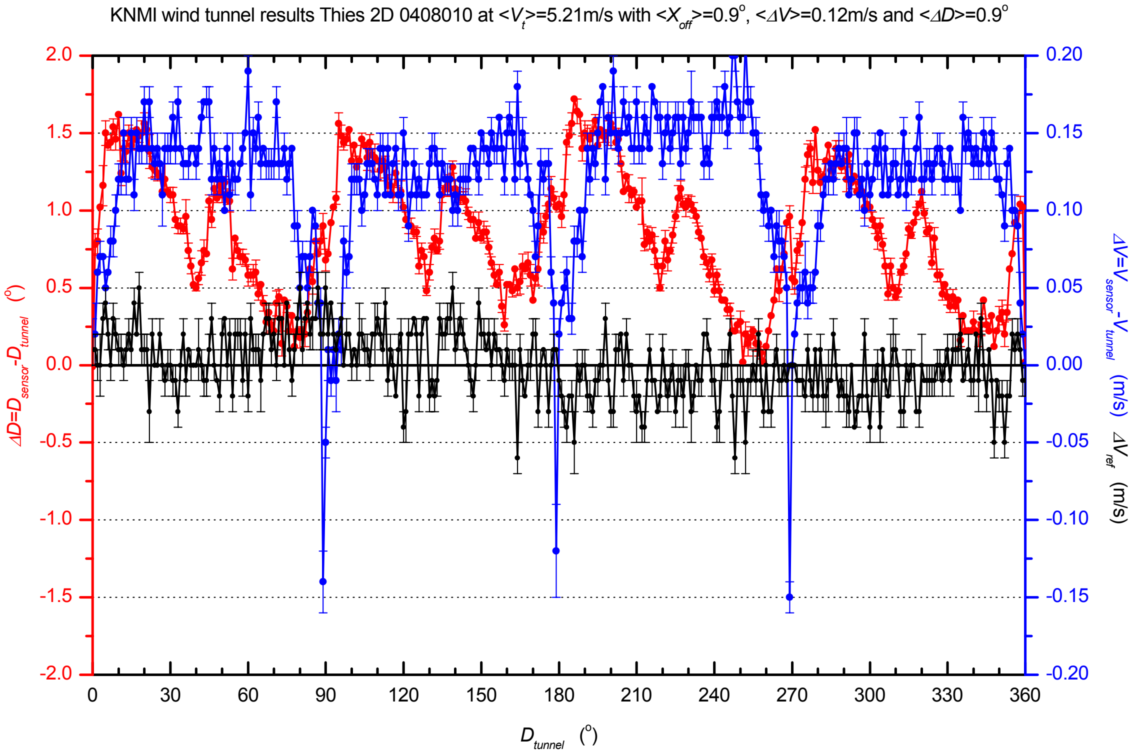

Figure 2: Differences between the Thies 2D and the KNMI tunnel reference for wind speed (blue) using the blocking factor for the KNMI cup anemometer and wind direction (red) as a function of the azimuth angle with a fixed tunnel speed. The variations in the tunnel reference speed are given in black. The error bars show the standard deviation of the 5 individual measurements at each azimuth angle.

The KNMI wind tunnel tests of the 10 Thies 2D sensors show a good reproducibility (cf. Figure 3a). The sensors show an offset in the wind direction <X_{off}> ranging between -0.4 and 0.8° and 1.3° for sensor 12. The sensor offset in wind direction is nearly independent of wind speed. The results for the wind direction are nearly identical for all 10 sensors and all wind speed once correction for the <X_{off}> has been applied (cf. Figure 3b). The wind direction shows a good reproducibility and a 90° symmetry. The deviation is a sine with a secondary feature around 45° with an overall amplitude of about 2°. Only sensor 12 shows a deviation from the 90° symmetry resulting in an overall amplitude of the deviations in wind direction of about 4° for low wind speeds. This behaviour is reproducible, but the reason is unclear. Since the deviations in wind direction are very similar for all sensors and nearly independent of wind speed, the reproducibility of the sensors has been investigated w.r.t. the averaged deviation for this batch of sensors. Once the sensor and wind speed independent azimuth correction has been applied the deviations are within about ±0.5° for all sensors, speeds and angles, expect for sensor 12 at 1 and 2 m/s and some isolated spikes (cf. Figure 3c). Nearly all sensors show isolated spikes at some azimuth orientation. This occurs mainly for the higher wind speeds and generally affects both wind direction and speed. Often the standard deviation of the 5 measurements is larger during that situation. The cause of this is probably a disturbance of the wind field resulting from the relatively small size of the wind tunnel as compared of the sensor.

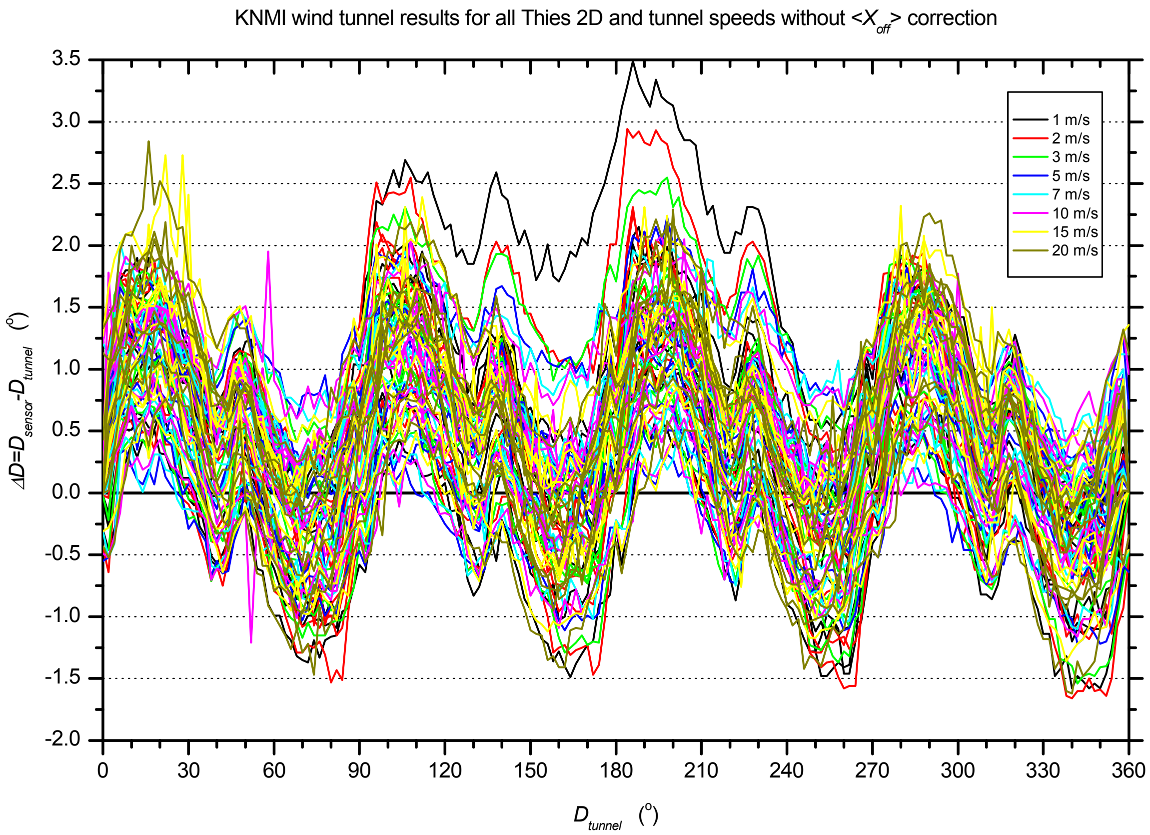

Figure 3a: Deviation of wind direction for all 10 Thies 2D and all 8 wind speeds as measured.

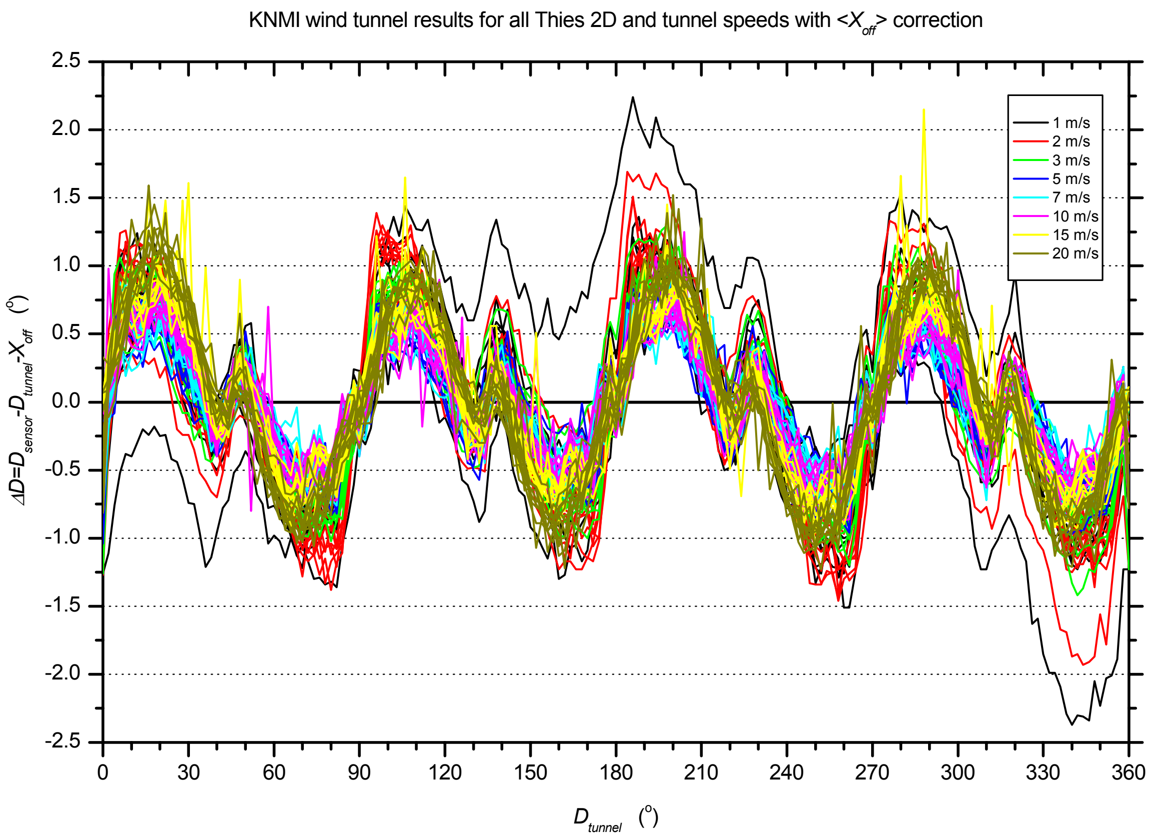

Figure 3b. As Figure 3a, but with <X_{off}> correction per sensor.

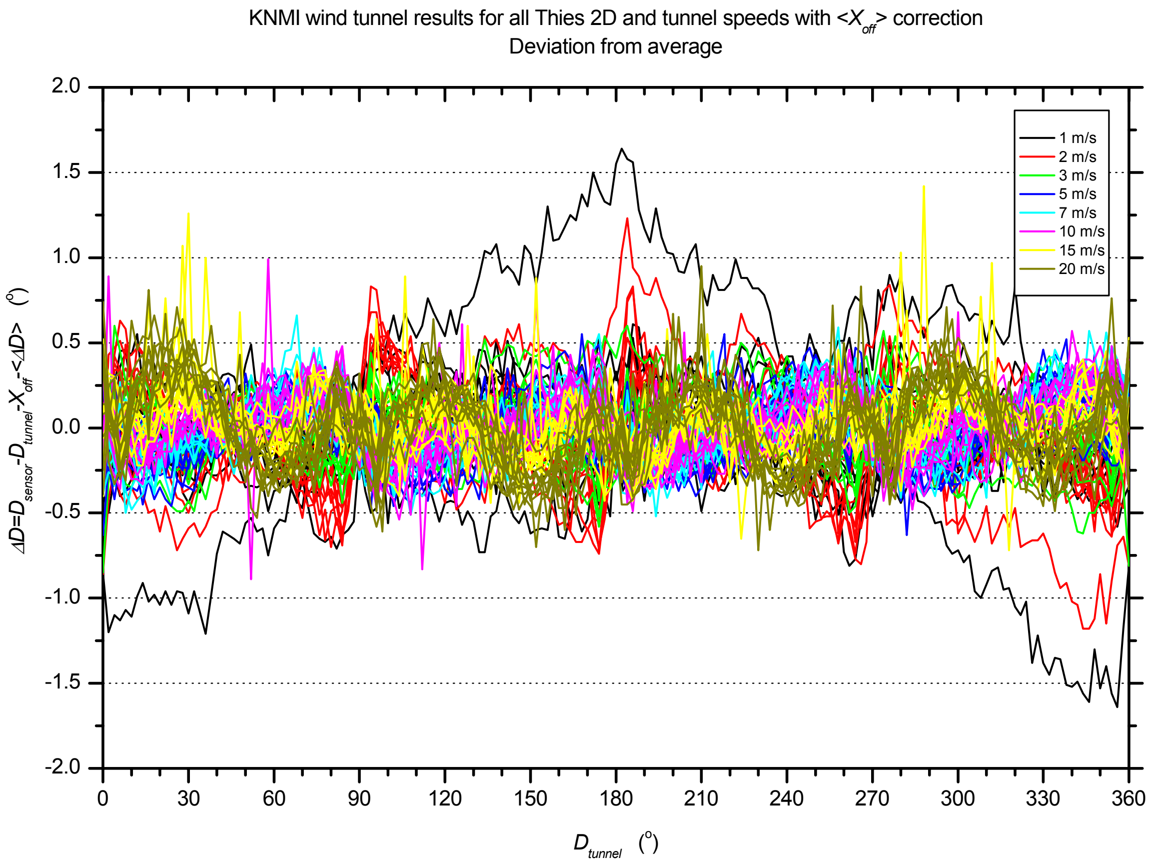

Figure 3c: As Figure 3a, but deviation from overall average after <X_{off}> correction per sensor.

The wind speed results for the 10 Thies 2D sonics obtained in the KNMI wind tunnel are given in Figure 4a. The differences in wind speed reported by the sensor en tunnel reference are generally small and increase slightly with wind speed (typically +0.05m/s at 1m/s and +0.4ms/ at 20m/s). However, the deviation increases suddenly when the wind speed is nearly parallel to a transducer pair. This mainly occurs for the higher wind speeds 15 and 20m/s, but for some sensors the features occur already at lower wind speeds. The deviation is maximally about −0.7m/s at 20m/s. Note that the differences in amplitude of these peaks between sensors is related to the differences in the offset in the wind direction between sensors since the value (and also the correction applied in the sensor) changes rapidly if the wind direction changes slightly around these angles (cf. Figure 2). The deviation in wind speeds show relatively small differences between the sensors, but the deviations vary with wind speed. In this case a wind speed and azimuth dependent correction needs to be applied in order to reduce the deviations within about ±0.1m/s for all sensors, speeds and angles, but deviations up to ±0.4m/s occur for some sensors at 0, 90, 180, and 270°. Once a correction has been applied for the azimuth offset of the sensors the deviations in wind speed at 0, 90, 180, and 270° will probably reduce. The dependency on wind speed is probably the result of the incorrect blocking factor of the Thies 2D in the relatively small measurement section of the KNMI wind tunnel.

The virtual temperature of the Thies 2D sonics has been verified in the KNMI climate chamber (Figure 5). The temperature has been verified between -25 and 40°C. Below 20°C the relative humidity was left free, but at 20°C and higher temperatures relative humidity's of 30, 70 and 99% were considered. During the tests the sensor readings were taken when the climate chamber was stable. During the tests the ventilation of the chamber was on, but the results showed no significant differences when the ventilation was temporarily switched off. The observed differences between sonic virtual temperature and climate chamber reference largely follow the expected behaviour (Kaimal and Gaynor, 1991). A temperature (and humidity) dependency can still be observed in the differences after transformation of virtual into ambient temperature (cf. Figure 6). This is caused by a change in the distance between the transducer pairs, although the change in distance should be larger than could be expected from the thermal expansion of stainless steel alone. Lanziger and Langmack (2005) measured the distance between the 2 transducer pairs of a Thies 2D sonic wind sensor and observed higher values than could be expected by thermal expansion. The values reported by Lanziger and Langmack nearly explain the observed differences completely, when assuming that the distance calibration of the manufacturer is performed at near 10°C. The results for 2 Thies 2D in this respect are nearly identical and independent of whether the sensor is heated or not.

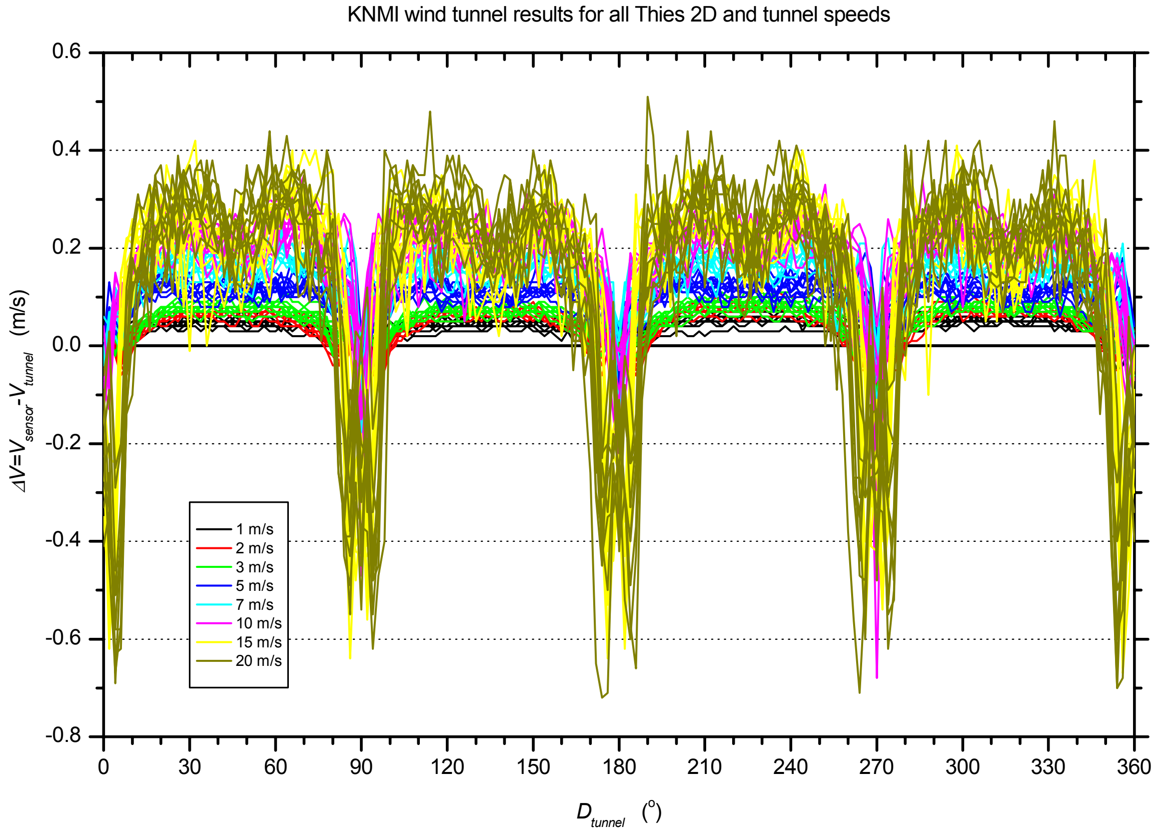

Figure 4a: Deviation of wind speed for all 10 Thies 2D and all 8 wind speeds as measured.

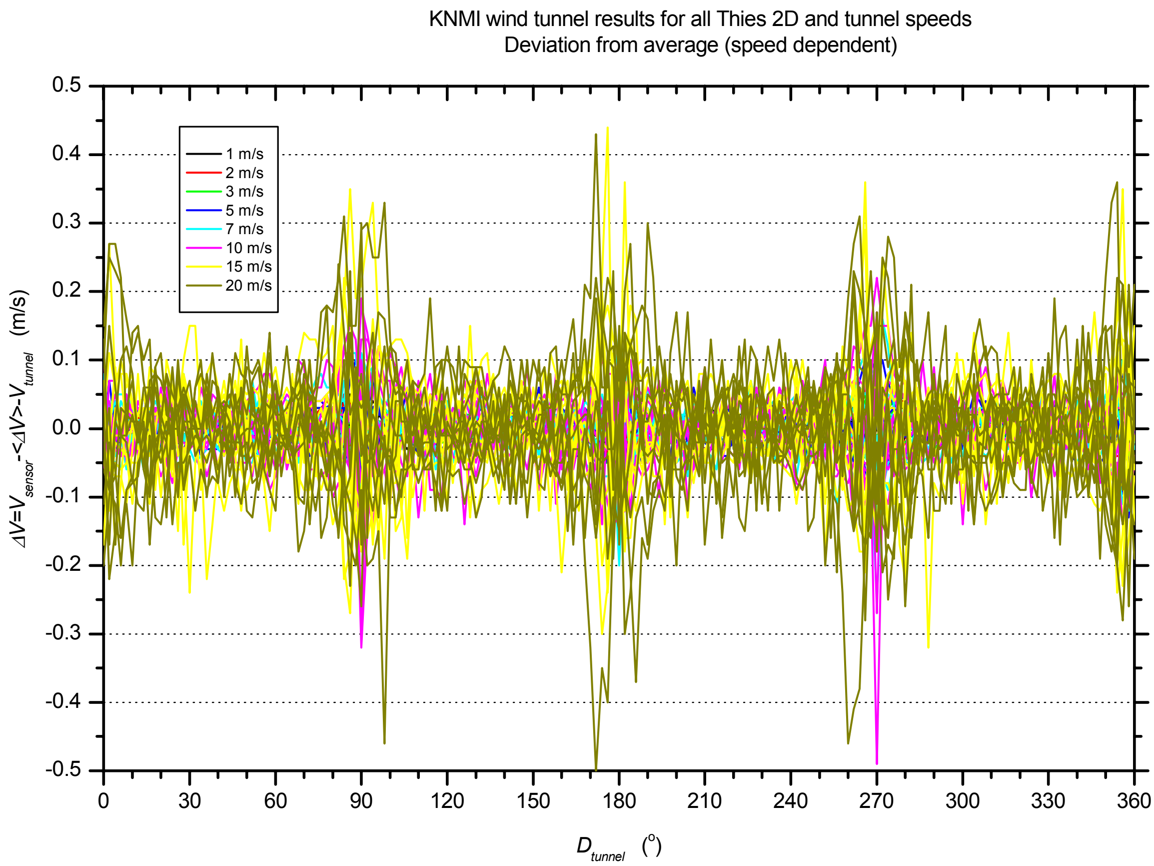

Figure 4b: As Figure 4a, but showing deviation from the wind speed dependent average.

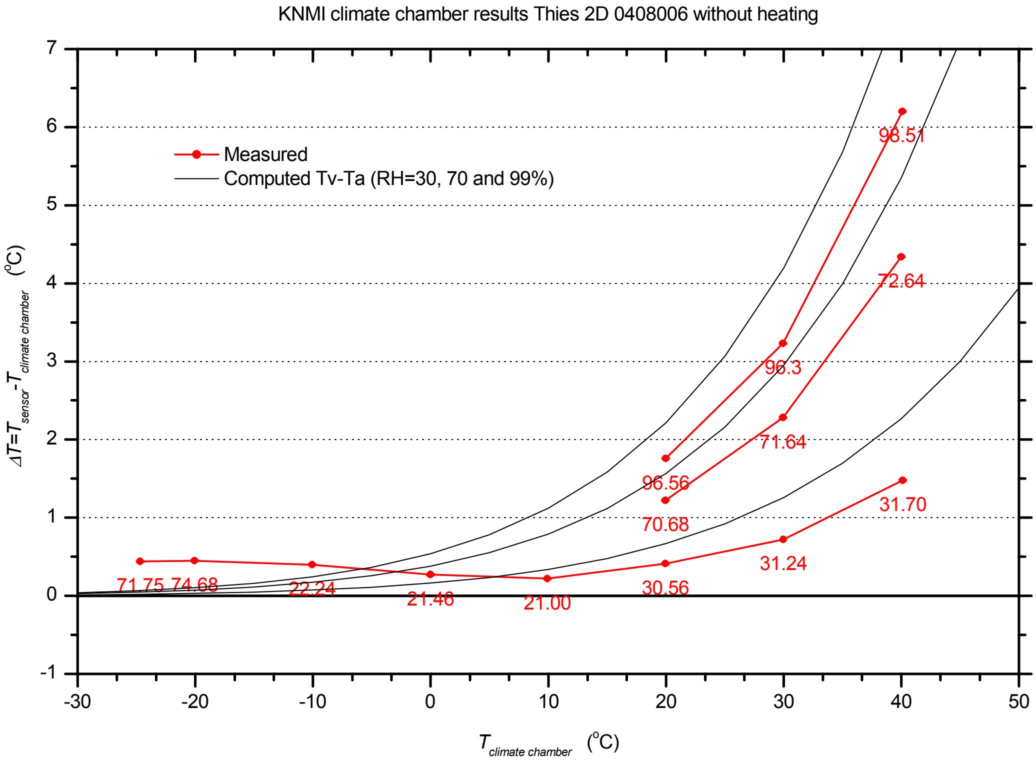

Figure 5: Differences between Thies 2D virtual temperature and the reference temperature of the KNMI climate chamber. The relative humidity is denoted by red numbers. The black lines indicate the expected deviation between virtual and ambient temperature for 99, 70 and 30% RH.

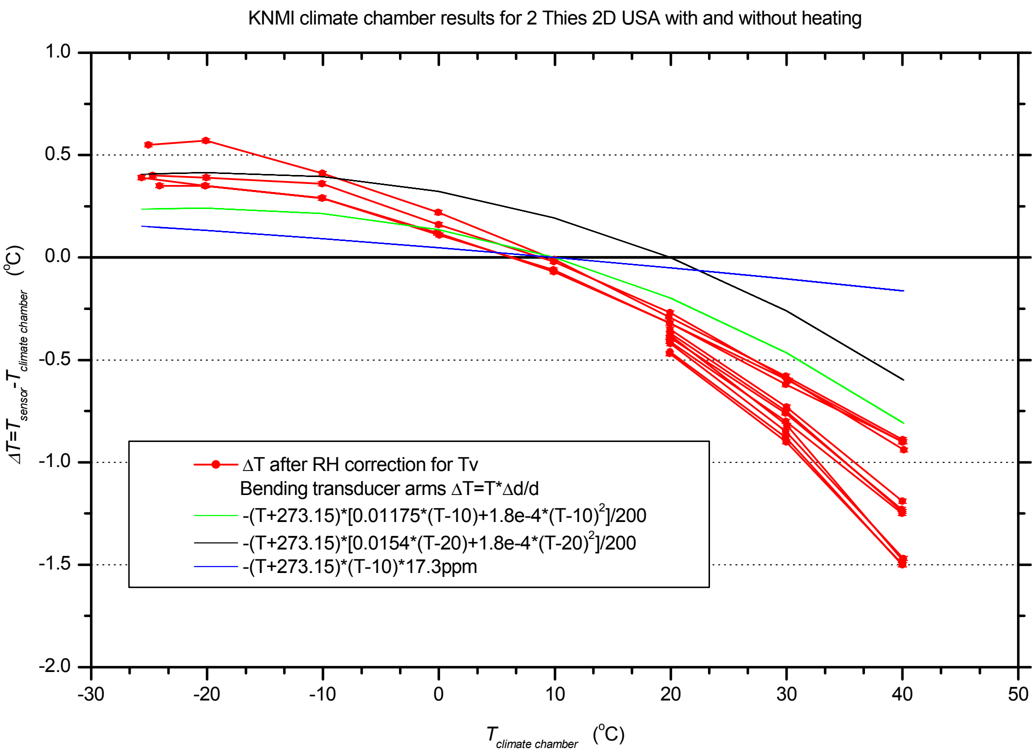

Figure 6: Temperature dependency of temperature difference between Thies 2D and KNMI climate chamber (red), the differences expected from thermal expansion of stainless steel (blue), and the observed change in distance between the transducers as a function of temperature (Lanziger and Langmack, 2005).

3. FIELD TEST

During the field test the 10 2D sonic wind sensors will be placed in parallel with the operational wind vane and cup anemometer of KNMI. The preparations for the operational tests are almost completed. The KNMI sensor interface is ready and the construction for the mounting of the sonic has been prepared. The realisation of the setup will start in September 2008. The locations for the operational test are indicated in Figure 7. Lichteiland Goeree is a platform and IJmuiden a pier where high wind speeds are observed in a saline environment. The same is true for Vlieland (Vliehors) where the measurement site is located on a sandbar. Schiphol (18R) is a civil airport and Volkel (main) is an airbase where noise and vortices by aviation can be expected. Hupsel is an inland station with low wind speeds and the highest occurrence of solid precipitation. Vlissingen and De Bilt are climatological stations with long historical records and high variations in surface roughness. At both these locations the wind is measured at 20m. In De Bilt an additional measurement will be performed at 1.5m. Cabauw is the research site of KNMI with optimal measurement conditions. Two new 10m masts will be placed at Cabauw. One mast will contains the KNMI wind vane, cup anemometer and Thies 2D. The other mast will contain the Thies 3D, Gill R3-100 and Gill Windmaster Pro. The distance between the sensors is 1m and the sensors are aligned in a line perpendicular to the prevailing wind direction (South West).

Figure 7: The locations of the operational test of 10 2D sonics in the Netherlands.

4. CONCLUSIONS AND OUTLOOK

The 10 Thies 2D sonic wind sensors have so far only been tested in the relatively small KNMI wind tunnel. De results of the sonics showed good agreement and reproducibility. The wind direction, after correction for the angular offset of each sensor, showed a sensor and wind speed independent behaviour with an amplitude of about 2°. The reproducibility for each sensor and wind speeds between 1 and 20m/s is generally within ±0.5°. One sensor deviates from this behaviour at low wind speeds and will be investigated by the manufacturer in more detail. The wind speed results again show good reproducibility, but show a dependency on wind speed. However, note that the Thies 2D blocking factor in the KNMI wind tunnel has not yet been determined. Note that the observed differences between sensor and wind tunnel, although reproducible, might be caused by the disturbance of the air flow in the relatively small measurement section of the KNMI wind tunnel.

Wind tunnel tests of the Thies 3D and Gill Windmaster Pro showed that the KNMI wind tunnel is not suitable for a verification of the calibration of these sensors. The measurement cross section of these sensors has nearly the same size as the measurement area and small changes in the sensor position affect the results significantly. Furthermore the vertical wind component is of the same are of magnitude as the observed differences and varies considerably with the sensor azimuth angle.

The virtual temperature reported by the sonic wind sensors has been verified in the KNMI climate chamber. The results of the Thies 2D and Thies 3D agree reasonable well with the reference temperature after compensation for the relative humidity dependency of the virtual temperature. An additional correction for the temperature dependency of the distance between the transducers is required in order to bring the temperature agreement within about ±1°C. This correction is larger than could be expected from the thermal expansion coefficient alone, which is probably the result of stress. The Gill Windmaster Pro showed large temperature deviations which are currently under investigation by the manufacturer.

The work described in this paper is in progress. During the TECO it is expected that the LST and TNO wind tunnel results are available that should give information on the absolute calibration of the sonics and validity of the behaviour observed in the KNMI wind tunnel. Furthermore preliminary results of the field test should be available.

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