PO.179

Differential Temperature Measurement for Evaluating the Stability of the Atmosphere

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Project description

As part of the RealMe research project, funded by the German Federal Ministry of Economic Affairs and Energy, it has been researched whether the accuracy of common temperature sensors is good enough to evaluate the stability of the atmosphere by using differential temperature values to calculate the wind profile. The wind profile is essential to extrapolate the wind speed in greater heights, which are not measured with traditional met mast technology. Based on the stability of the atmosphere a correction term can be deduced to calculate the height profile of the wind speed.

The stability of the atmosphere is significantly influenced by the temperature gradient ($\nabla T_{Adiabatic} = -\left(\frac{\Delta T}{\Delta h}\right)_{Adiabatic} \approx \frac{1K}{100m}$) and the resulting vertical movement of the air. Those air parcels move up and down depending on air pressure p, temperature T, volume V and air density ρ (see Figure 1). The cooling down of the soil and the warming of the soil by sunlight are examples for this affect.

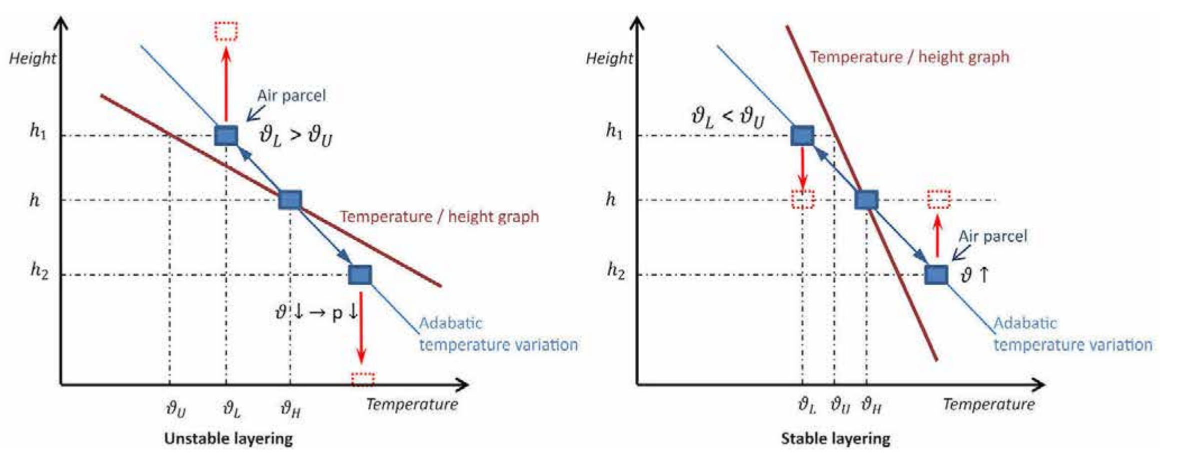


Figure 1: Formation of unstable and stable layering (related to Häckel, H.: Meteorology, 2012.)

Measurement instruments

During a 9-months measurement campaign the temperature measurement has been researched by installing three different sensor types. Active and passive temperature sensors as well as ventilated temperature sensors (Frankenberger method) have been installed, whereas the ventilated sensors provides a better accuracy than the active and passive temperature sensor.

Sensor	Label	Height	Tolerance
Active temperature	TH1	105m	± 0.2K
Active temperature	TH4	20m	± 0.2K
Passive temperature (Pt1000)	T2	105m	± 0.15K
Passive temperature (Pt1000)	T5	20m	± 0.15K
Ventilated temperature	T3 (vent.)	105m	± 0.1K
Ventilated temperature	T6 (vent.)	20m	± 0.1K

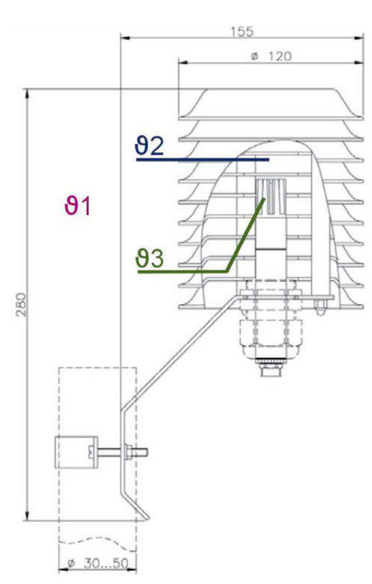


Figure 2: Sensor with weather and radiation shield
ϑ1 ambient temp.
ϑ2 temp. in the protection shield
ϑ3 temp. at the sensor

Commonly active temperature sensors are used for resource assessment. Passive measurement instruments with Pt1000 element are not so often installed, although offering a better tolerance. Both sensor types are built in a weather/radiation shield, which protects the sensor from rain and direct sun radiation while keeping it ventilated. Due to this construction a microclimate develops within the protection shield (Figure 2). Thus influencing variables such as wind speed, rain and sun radiation have been measured additionally.

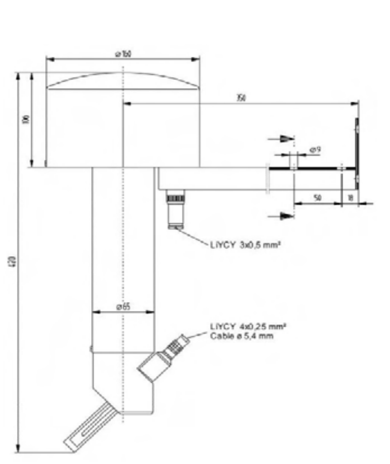


Figure 3: Ventilated Frankenberger sensor

The third sensor installed is a passive Pt100 Frankenberger sensor (Figure 3), which is constantly ventilated and protected against rain, wind and sun radiation. Due to its high price and power supply demand the sensor is not used for site assessment so far. This sensors has the best accuracy compared to the other sensors used in the project.

Measurement campaign

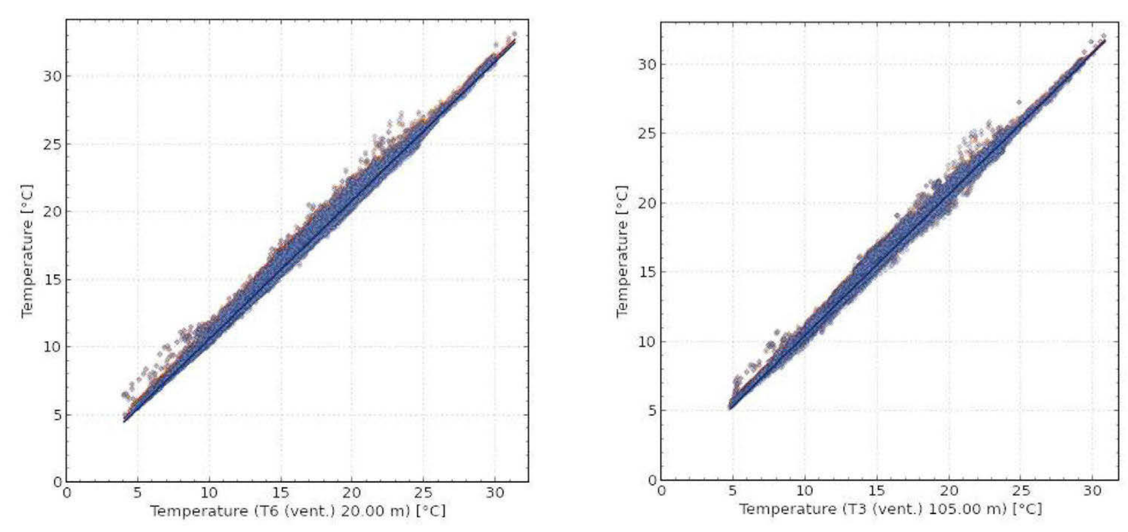
The temperature sensors have been installed on a 120m met mast in Lelystad (The Netherlands) on two heights: 20m and 105m in the same configuration. Active and passive temperature sensors are mounted on one boom oriented 349° to the North, whereas the ventilated sensor is installed on a separate boom oriented 95° to the North. Wind speed, direction, precipitation and sun irradiation have also been measured.

Figure 4: Location (Google Maps) and sensor installation on Ecofys WTTS met mast

Analysis of measurement data

The online platform AmmonitOR has been used for data monitoring and generating the charts, which show temperature values of each sensor category as well as the differential temperature – without any data correction.

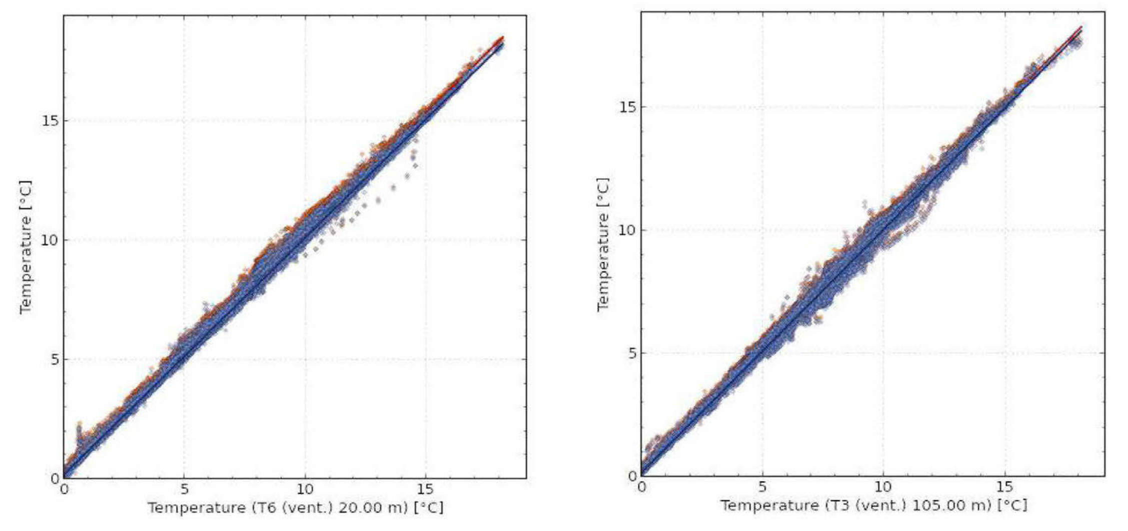
Correlation of seasonal temperature measurement data



Evaluation	Height [m]	Orientation [°]	R²	m	b
T6 (vent.)	20.00	95.00			
T5	20.00	360.0	0.994	1.024	0.672
TH4	20.00	360.0	0.993	1.026	0.384

Evaluation	Height [m]	Orientation [°]	R²	m	b
T3 (vent.)	105.0	95.00			
T2	105.0	358.0	0.994	1.014	0.557
TH1	105.0	358.0	0.994	1.018	0.338

Figure 5: Temperature correlation (2015-05-01 to 2015-08-31)



Evaluation	Height [m]	Orientation [°]	R²	m	b
T6 (vent.)	20.00	95.00			
T5	20.00	360.0	0.998	1.000	0.379
TH4	20.00	360.0	0.998	0.994	0.201

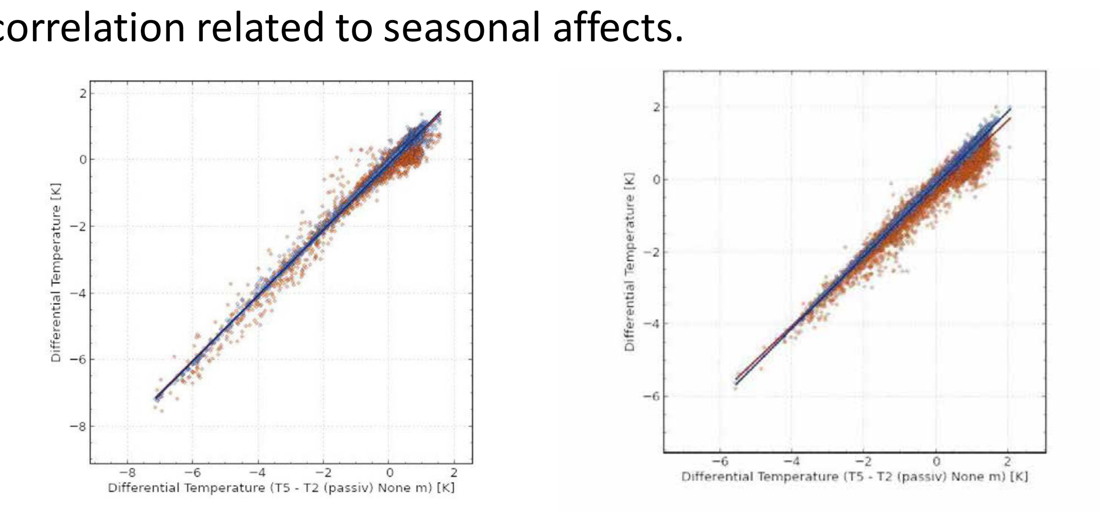
Evaluation	Height [m]	Orientation [°]	R²	m	b
T3 (vent.)	105.0	95.00			
T2	105.0	358.0	0.998	0.993	0.284
TH1	105.0	358.0	0.997	0.989	0.179

Figure 6: Temperature correlation (2015-11-01 to 2016-02-01)

The measured data of the different sensors at each height are very similar with very good correlation (R^2=0.994) at both heights. In the winter season the correlation has been even better with R^2=0.998. Wind speed and direction do not affect the temperature measurement.

Correlation of seasonal differential temperature data

While correlating the differential temperature of the sensors, the active and passive sensors correlated very good with R^2=0.998, whereas the more accurate ventilated sensor correlated only with R^2=0.966. There is no difference in the correlation related to seasonal affects.



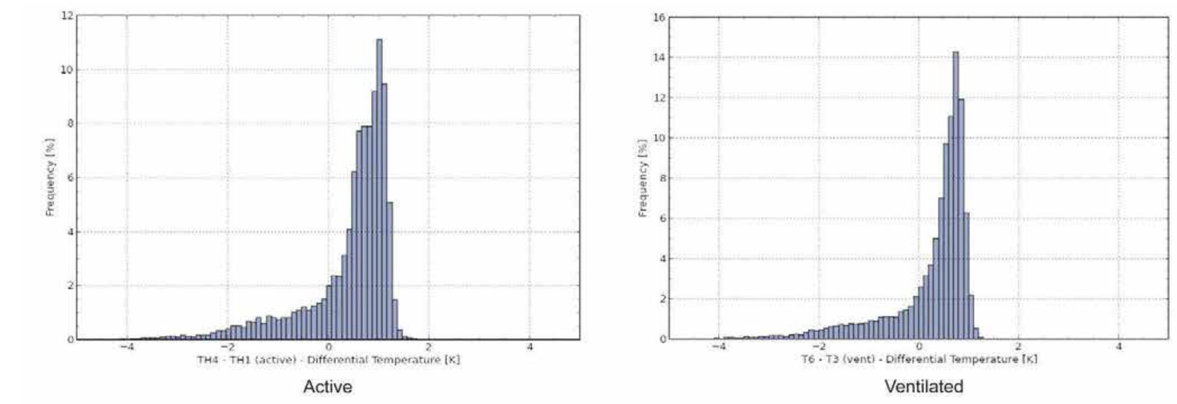
Evaluation	Height [m]	Orientation [°]	R²	m	b
T5 - T2 (passiv)					
T6 - T3 (vent)			0.960	0.977	-0.142
TH4 - TH1 (active)			0.996	0.990	-0.088

Evaluation	Height [m]	Orientation [°]	R²	m	b
T5 - T2 (passiv)					
T6 - T3 (vent)			0.966	0.948	-0.240
TH4 - TH1 (active)			0.998	1.000	-0.096

Figure 7: Correlation of differential temperature (2015-11-01 to 2016-02-01) and (2015-05-01 to 2015-08-31)

Seasonal histograms of differential temperature

The histograms show that during summer there is a broader range of values whereas the differential temperature for the winter is quite close for each sensor type.



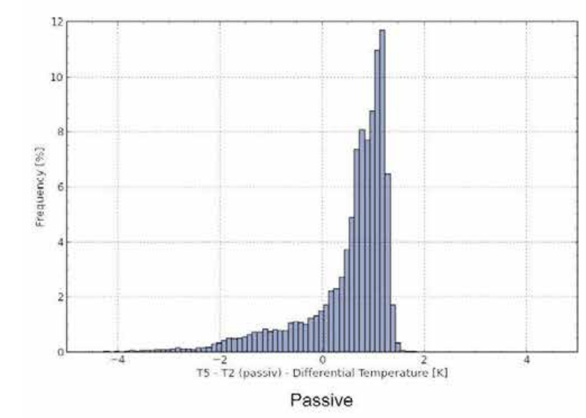
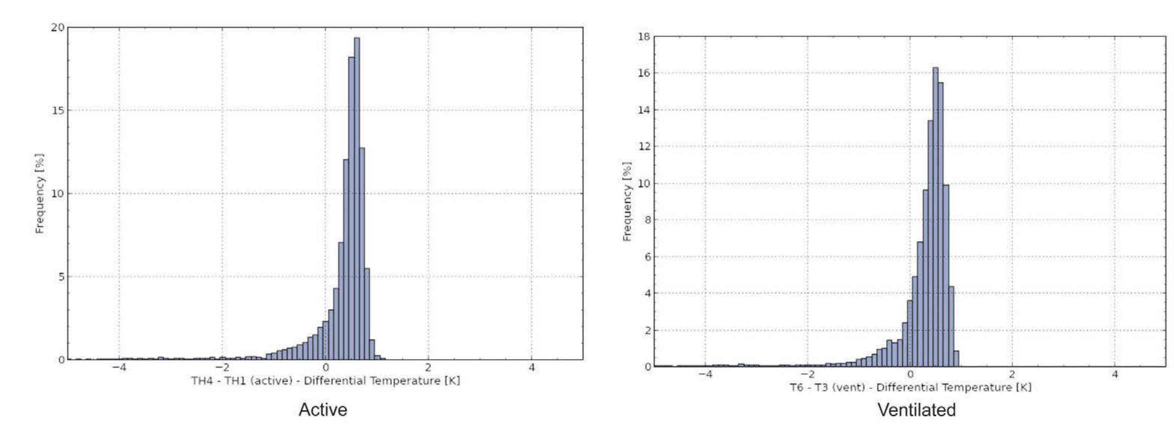


Figure 8: Histograms of differential temperature (2015-05-01 to 2015-08-31)

	< 0	> 0	Sum
Active	21.59	78.412	100.002
Ventilated	25.147	74.855	100.002
Passive	19.193	80.803	99.996
Average	21.977	78.023	100.000

Summary in %



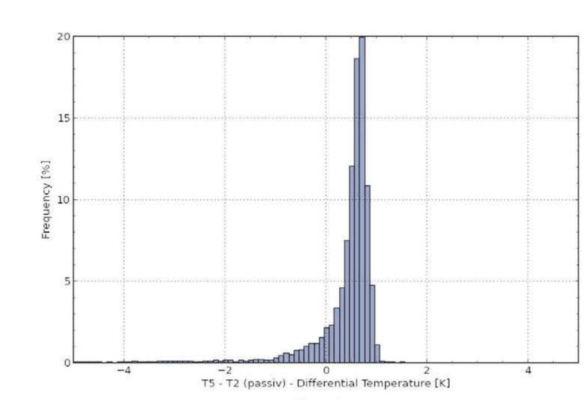


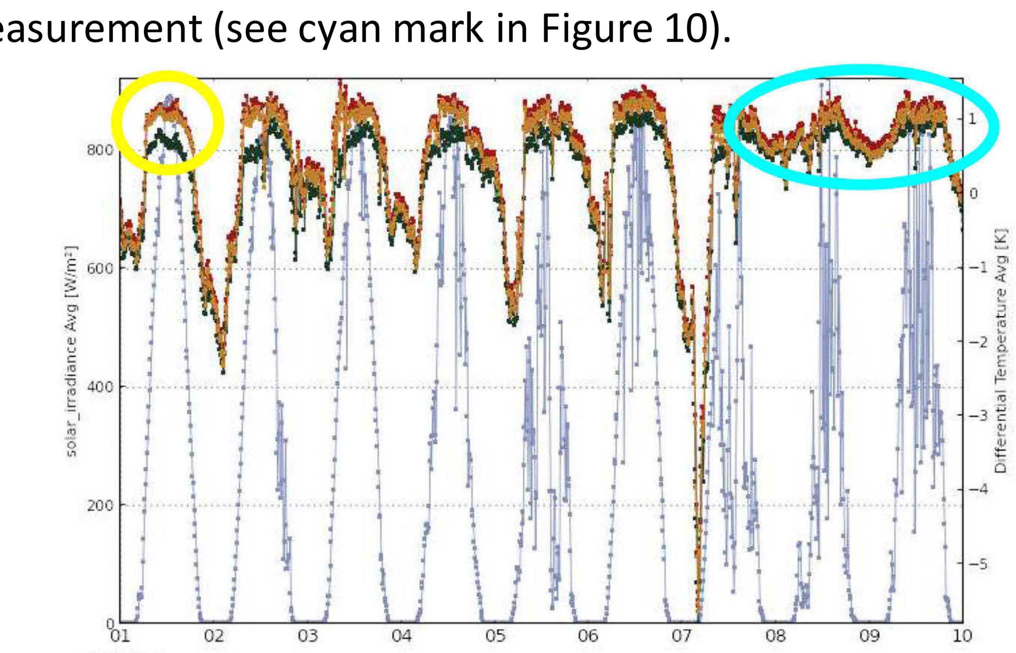
Figure 9: Histograms of differential temperature (2015-11-01 to 2016-02-01)

	< 0	> 0	Sum
Active	16.247	83.739	99.986
Ventilated	18.281	81.702	99.099
Passive	14.553	85.430	99.946
Average	16.360	83.624	99.677

Summary in %

Conclusions

The different temperature sensors show only minimal deviations in the measurement values. Wind speed, direction and precipitation do not affect the measurement, whereas direct sun radiation causes variations in the temperature measurement (see yellow mark in Figure 10). On cloudy days and during the night there are only marginal deviations in the measurement (see cyan mark in Figure 10).



	Type	Height [m]	Orientation [°]	Unit	Min (of Min)	Min (of Avg)	Avg (of Avg)	Max (of Avg)	Max (of Max)	Display (Marker)
Solar Sensor	solar_irradiance	5.000		W/m²	0.000	0.000	261.0	920.8	1274	Avg (o)
T5 - T2 (passiv)	Differential Temperature			K	-5.677	-5.567	0.485	1.546	1.824	Avg (o)
T6 - T3 (vent)	Differential Temperature			K	-6.290	-5.802	0.183	1.167	2.046	Avg (o)
TH4 - TH1 (active)	Differential Temperature			K	-5.737	-5.631	0.382	1.367	1.721	Avg (o)

Figure 10: Global Horizontal Irradiation vs. Differential temperature (2015-07-01 to 2019-07-10)

Active and passive temperature sensors show higher differential temperature values than the ventilated sensor on sunny days. It can be assumed that this affect is caused by the weather/radiation shield affecting sensors on both heights with the same intensity. Additionally, the sensors at 20m are influenced by the heat reflection from the ground.

The measured temperature trend of the installed sensor types can be used for temperature layering analysis. However, a final meteorological examination has to define whether the bins between ±0.5K and sensor-related errors are within an acceptable range for temperature layering analyses.