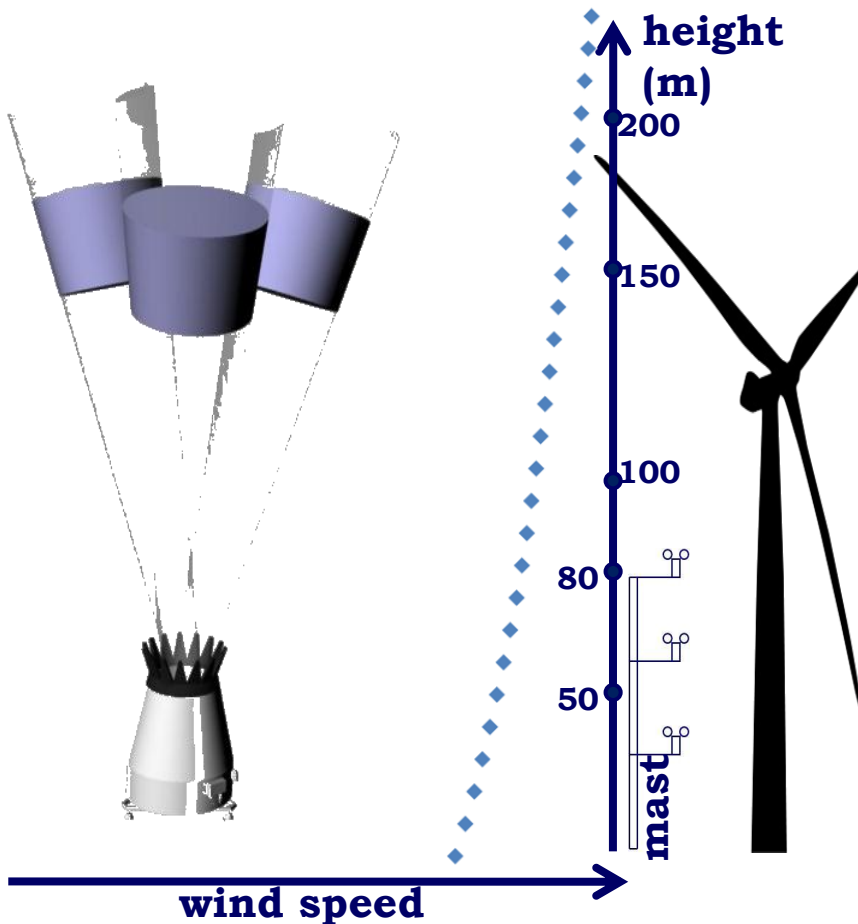


## Coupling Sodar measurements with WindSim: a test case

Matteo Gianni, Luigi Imperato  
[m.gianni@studiorinnovabili.it](mailto:m.gianni@studiorinnovabili.it)

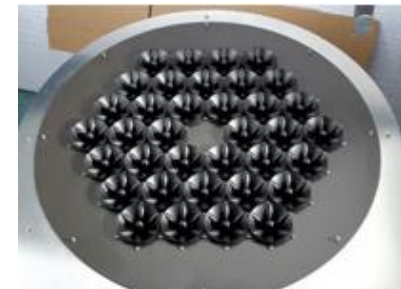
## SODAR Campaigns in wind energy: technology

Emitting acoustic pulses, the SODAR device can measure the wind vector at various levels, up to 200 m from ground



### Technologies:

- Phased arrays (electronically controlled)

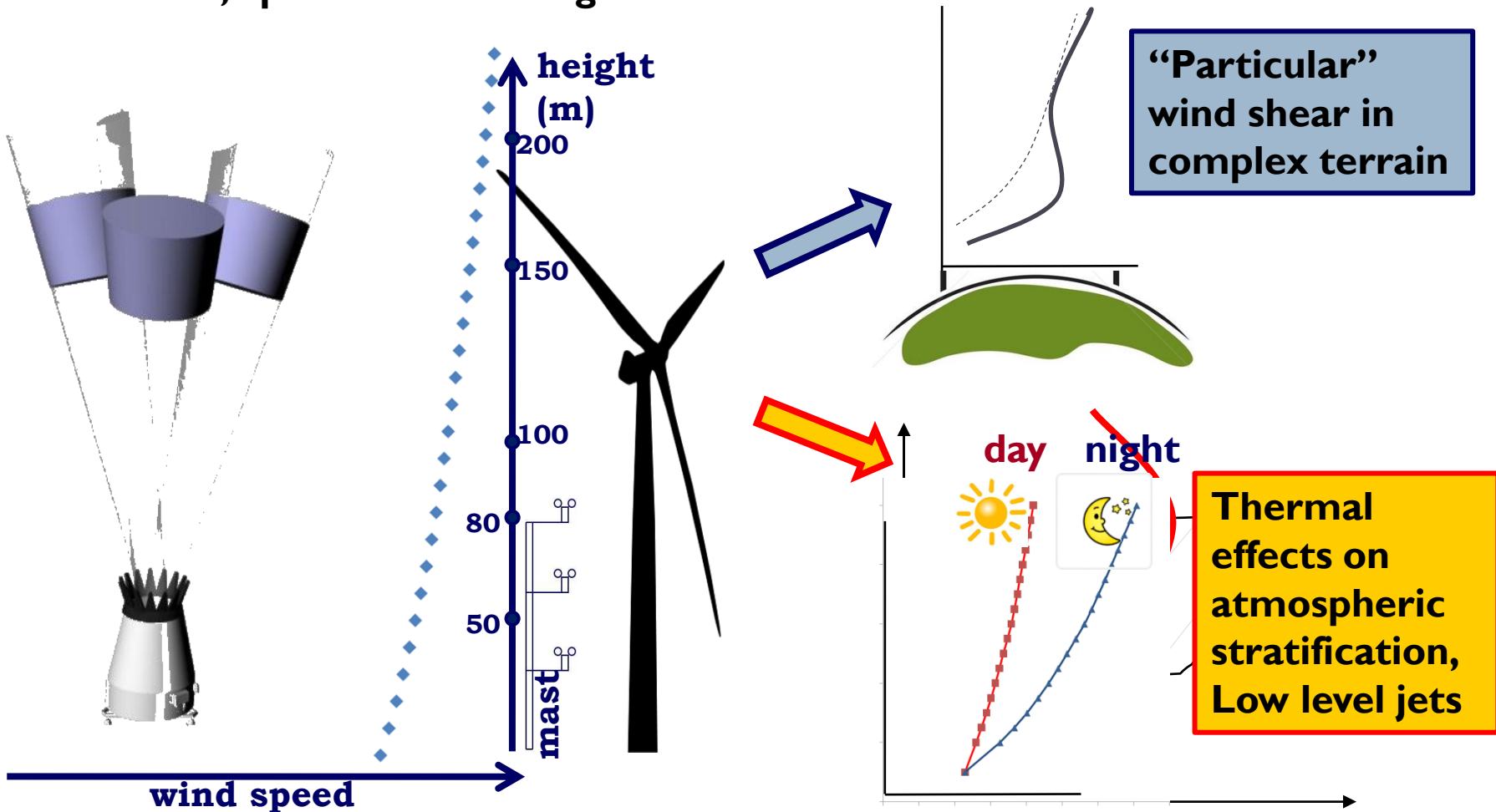


- 3 antenna configuration



# SODAR Campaigns in wind energy: possible use

Emitting acoustic pulses, the SODAR device can measure the wind vector at various levels, up to 200 m from ground



## Coupling SODAR measurements with WindSim

In the workflow of a typical wind resource assessment study with WindSim, SODAR measurements can be used to:

▪ Compare numerical and experimental wind profiles

if



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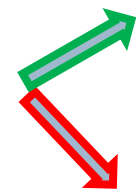


Reduce uncertainty  
(P50 unchanged)

if



,



Tune model till agreement  
(orography , roughness)  
(change P50 and uncertainty)  
Increase uncertainty

▪ Define new climatologies, by making correlations with on-site mast data



Reduce error (change P50)  
and uncertainty

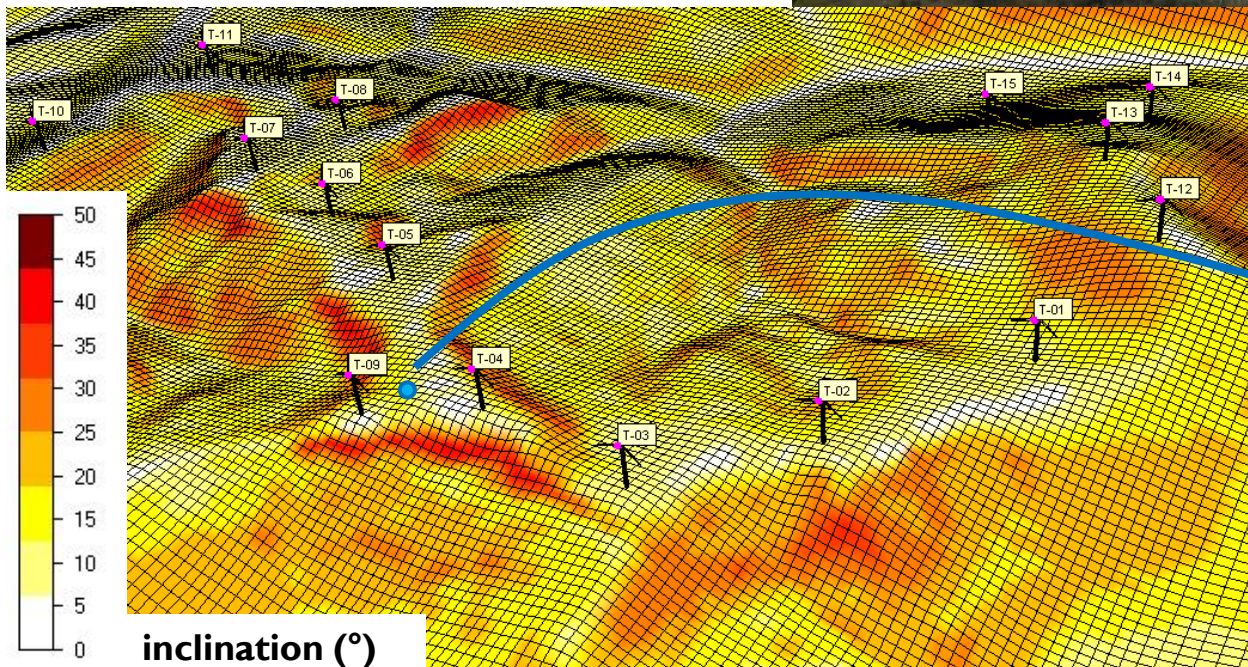
## Scenario of the test case

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- Wind farm project in the south of Italy, in complex terrain
- After 2-3 years of measurements with a 40 m mast, a consultant produced a wind assessment study, using a linear model, estimating the expected AEP
- The project was sold and, before financing the wind farm, a 80 m mast was installed
- Dramatic differences in the experimental wind profile from what expected, thus affecting around 30% of the AEP
- The owner performed a SODAR campaign to gain further insight on the wind shear across the site
- Meanwhile, we were commissioned a wind assessment study, using CFD and SODAR data.

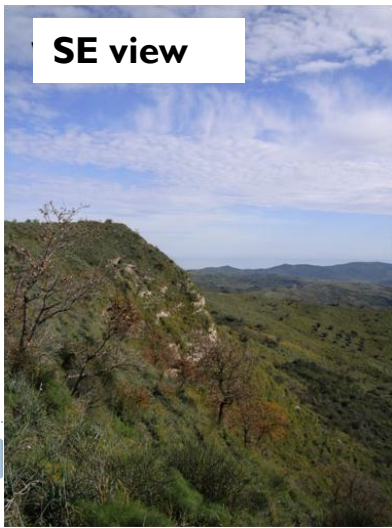
## Test case – General features

- south of Italy, complex terrain
- Simple vegetation
- Site Area: 2.3 km x 1.4 km
- Average height: 345 m a.s.l.

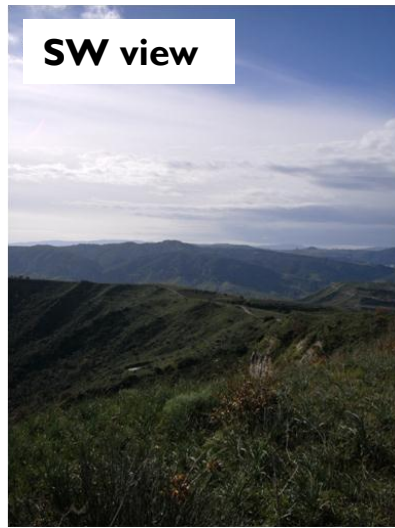


80 m lattice mast

# 80 m mast: experimental wind profile

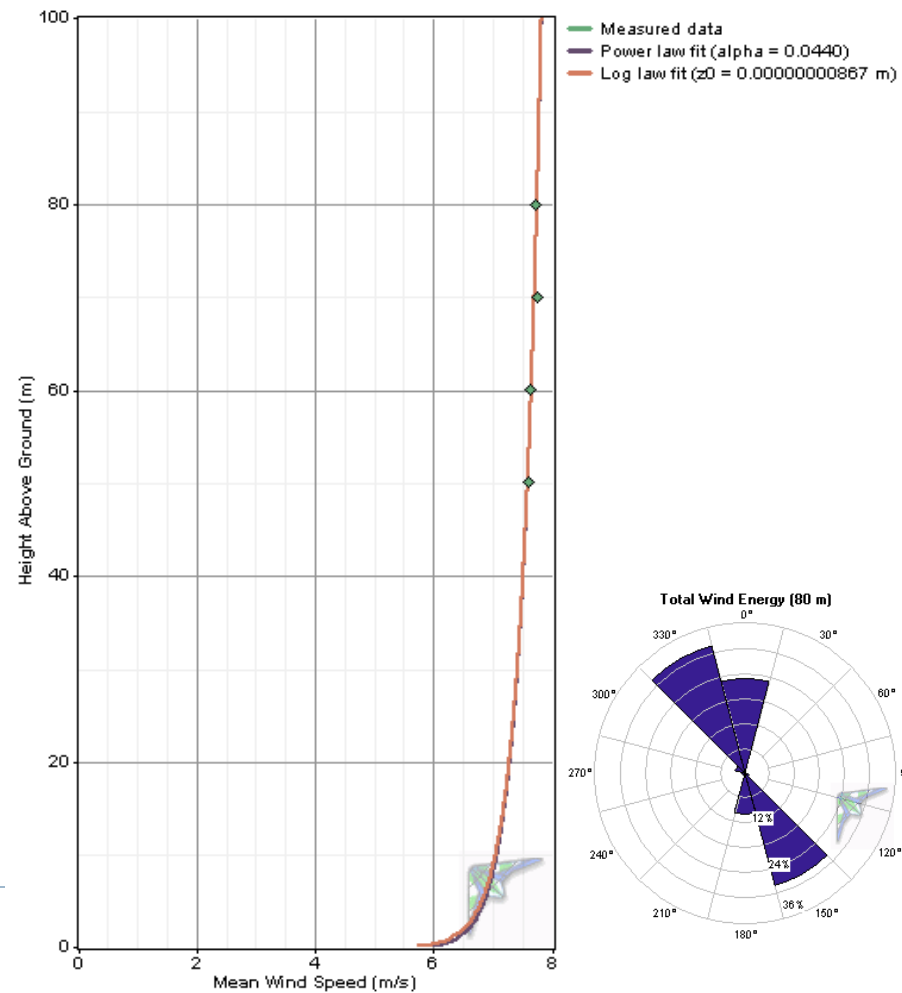


SE view



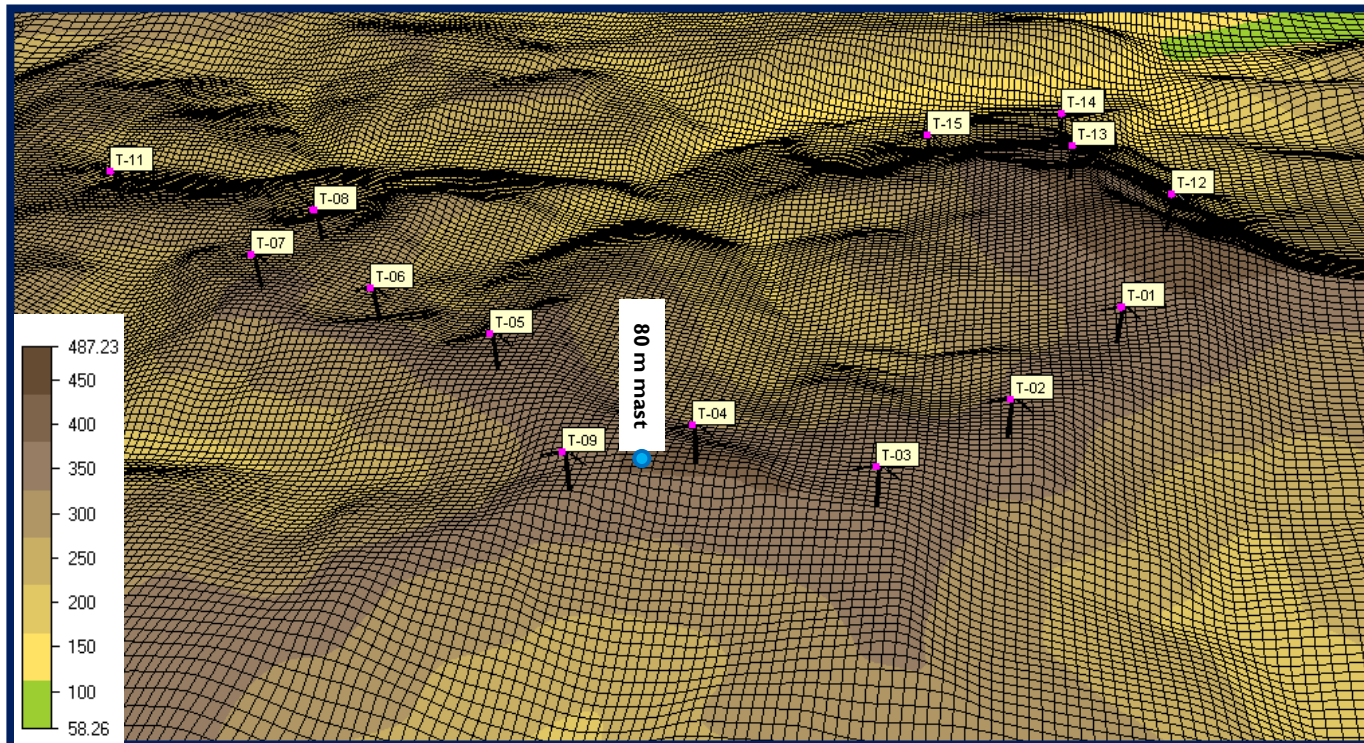
SW view

- Available time interval: 16 months
- 4 NRG #40C cup sensors
- Booms orientation:  $240^\circ$



# WindSim Model

- Orography model from terrain data with fine 5 m horizontal resolution
- Large model: 20 x 20 Km
- Nesting model: 8 x 7 Km
  - 2.6x10<sup>6</sup> cells, inner refinement with max resolution 15 m
- Vertical resolution : variable but at least 6 cells in the first 100 m height

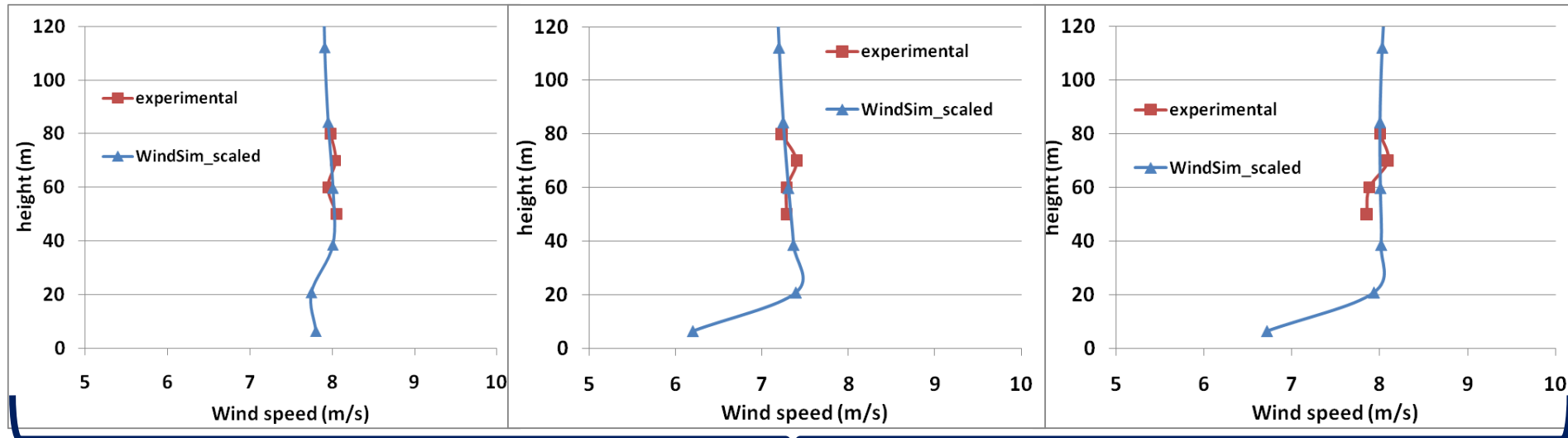


# Comparison of numerical and experimental profile in the 80 m mast position

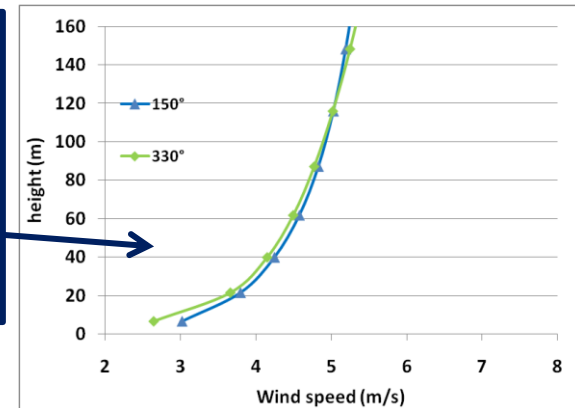
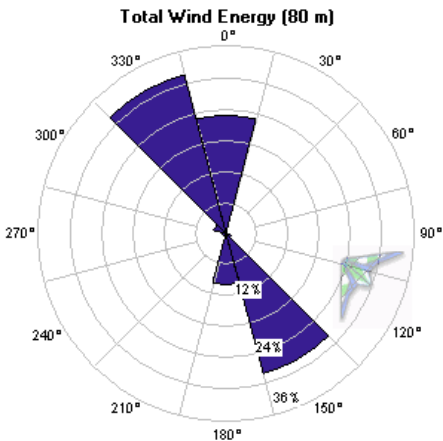
SSE: 135° - 165°

NNW: 315° - 345°

N: 345° - 15°



**WindSim model performs well, but uncertainty is still high, because the site is complex and there are locations where very different profiles are predicted**



## SODAR data – Position 1 – Installation and filtering

- A phased-array SODAR was firstly installed close to the 80 m mast (~ 70 m aside)



# SODAR data – Position 1 – Installation and filtering

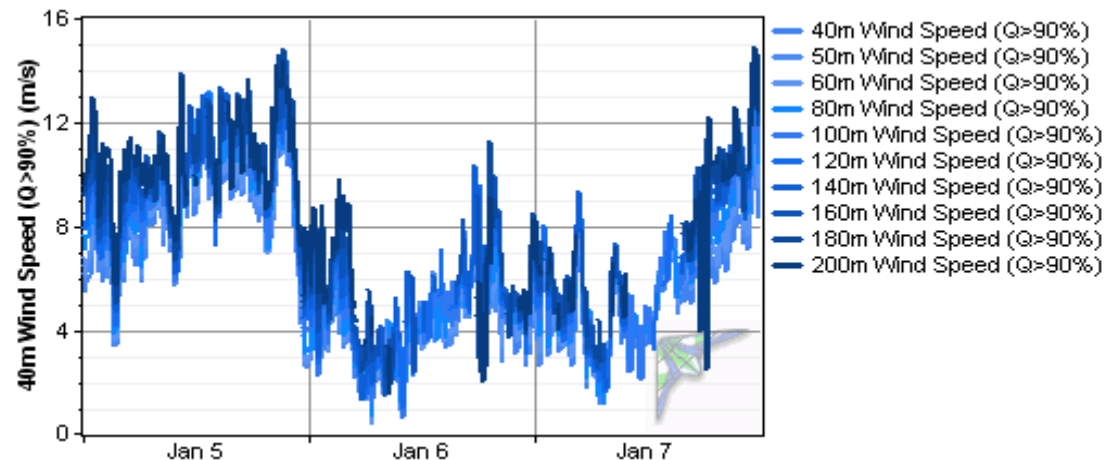
- A phased-array SODAR was firstly installed close to the 80 m mast (~ 70 m aside)



Some filtering is required:

- Minimum speed quality factor = 90%
- Minimum turbulence quality factor = 90%
- Minimum vertical speed = -1.5 m/s (rain) ; Max = 5 m/s
- Overall availability was ~ 88% in 1 winter rainy month

Example of typical output of the SODAR wind speed data

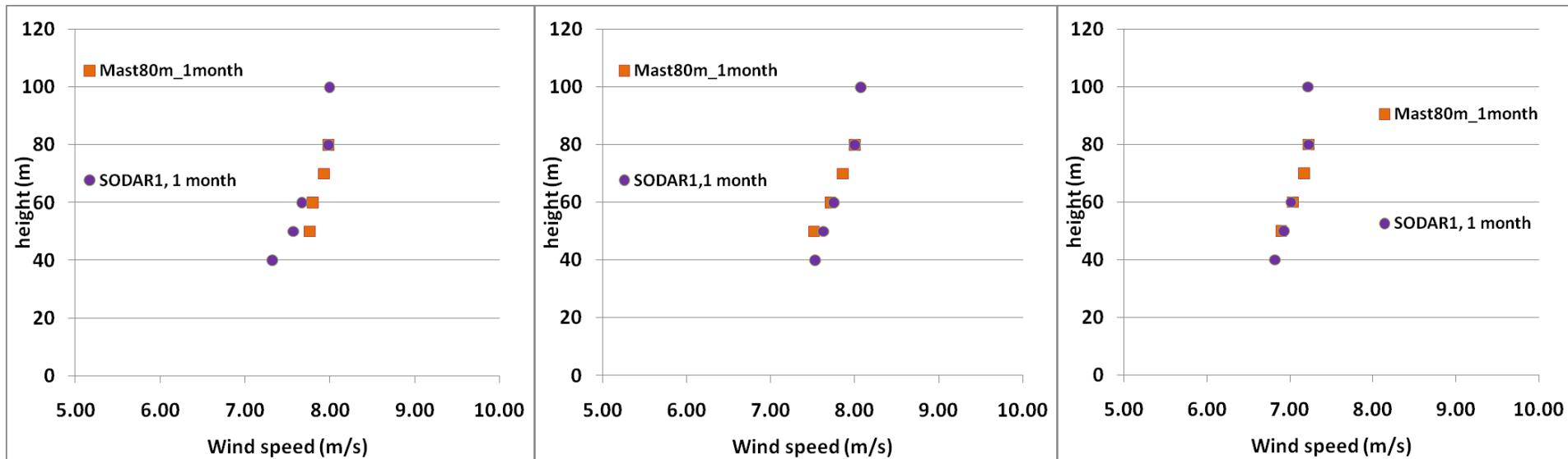


# SODAR data – Position 1 – comparison of vertical profiles

SSE: 135°- 165°

NNW: 315°- 345°

N: 345°- 15°



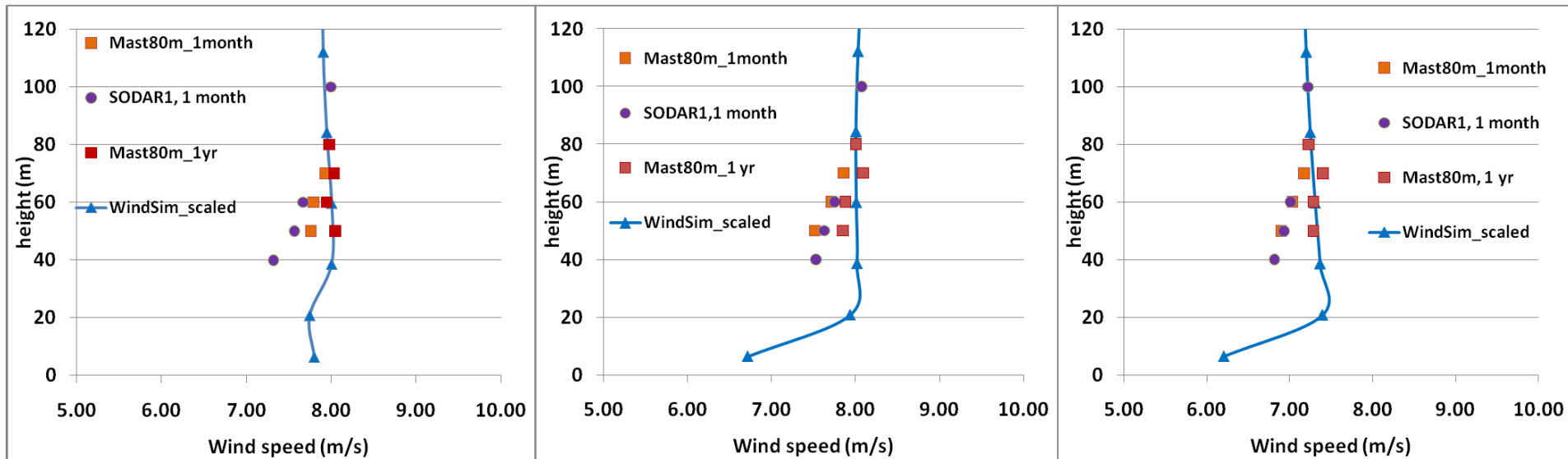
- In the prevailing sectors, SODAR detected profiles confirm the shear related to the 80 m mast measurements, as expected

# SODAR data – Position 1 – comparison of vertical profiles

SSE: 135°- 165°

NNW: 315°- 345°

N: 345°- 15°



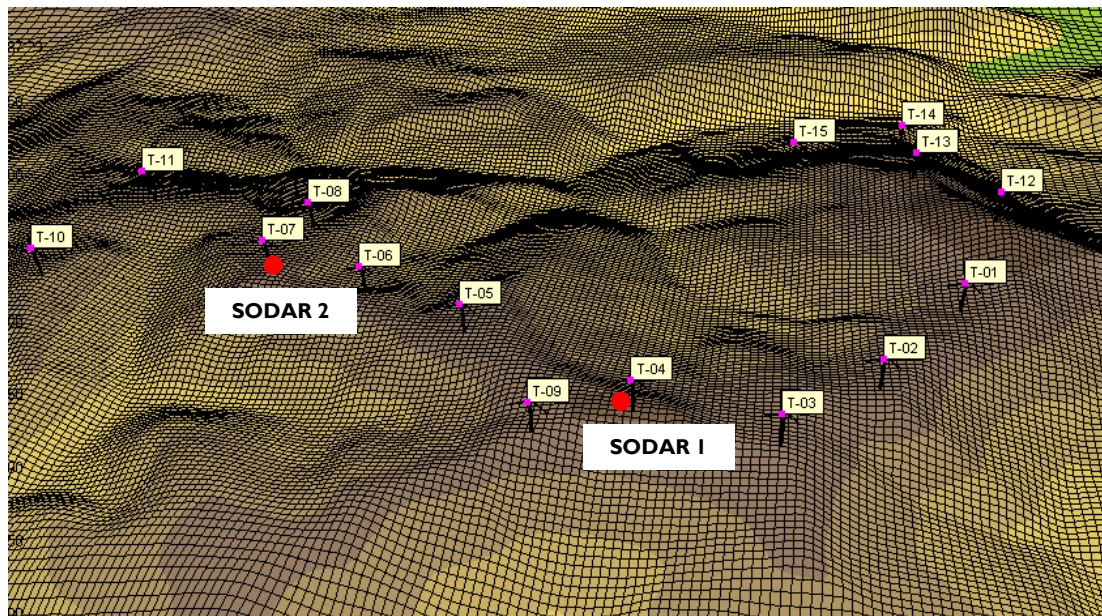
▪ In the prevailing sectors, SODAR detected profiles confirm the wind shear related to the 80 m mast measurements, as expected

▪ When considering the average yearly profile, a difference with monthly values is observed, thus meaning that in some cases seasonal variability may be strong, and the measuring intervals must be properly chosen.

## SODAR data – Position 2 - Installation

The SODAR was moved about 1.2 km away, in a position where:

- Orography is simpler, no steep slopes
- Different vegetation (surrounded by vineyards)
- Some turbine should be installed
- The CFD predicts a very different profile with respect to position I

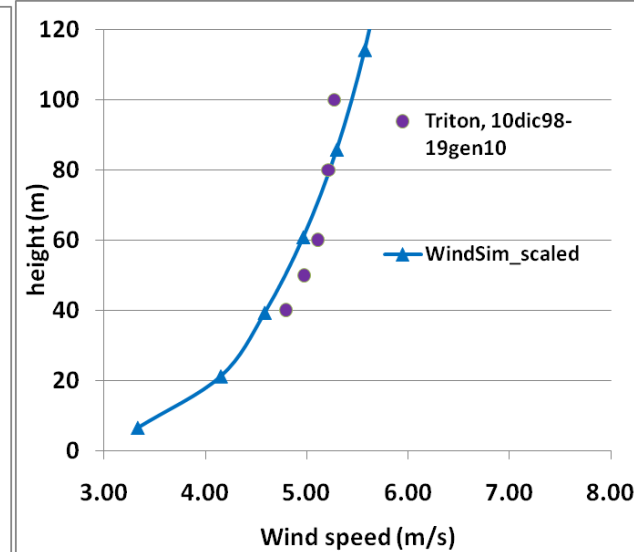
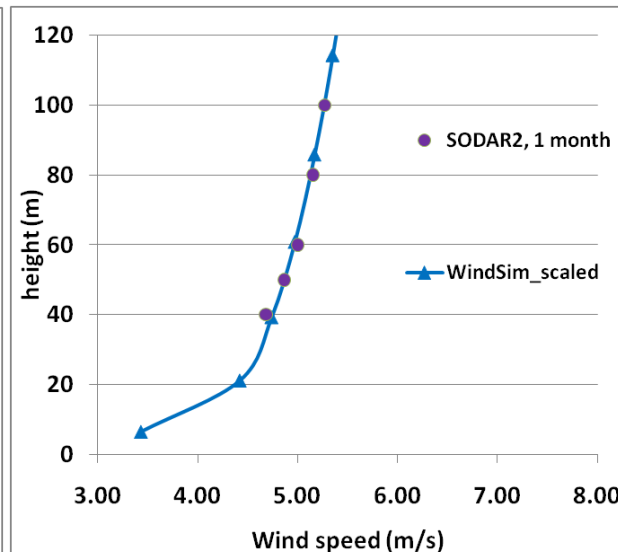
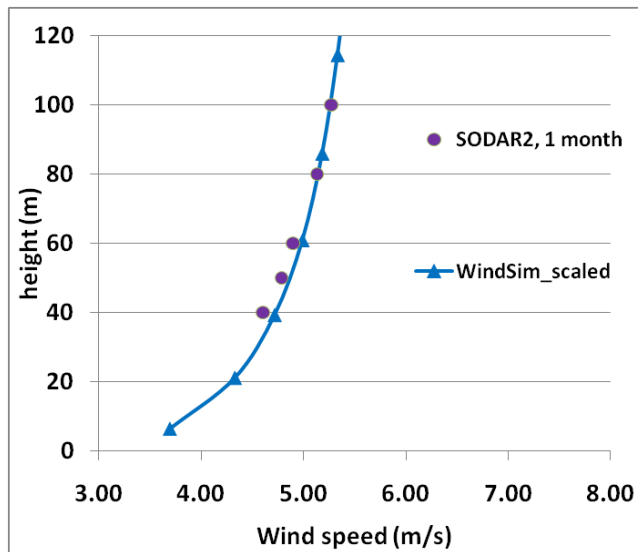


# SODAR data – Position 2 – comparison of vertical profiles

SSE: 135°- 165°

NNW: 315°- 345°

N: 345°- 15°



▪ In the prevailing sectors, SODAR detected profiles confirm the shear predicted by WindSim

▪ The same procedure was then repeated in a 3<sup>rd</sup> position. This works as validation of the CFD model, and allows reducing its uncertainty.

# Coupling SODAR measurements with WindSim

Going back to the coupling possibilities:

✓ **Compare numerical and experimental wind profiles**

if



,



**Reduce uncertainty  
(P50 unchanged)**

if



,



**Tune model till agreement  
(orography , roughness)  
(change P50 and uncertainty)**

**Increase uncertainty**

**Define new climatologies, by making correlations with on-site mast data**



**Reduce error (change P50)  
and uncertainty**

## Defining new climatologies using SODAR wind measurements

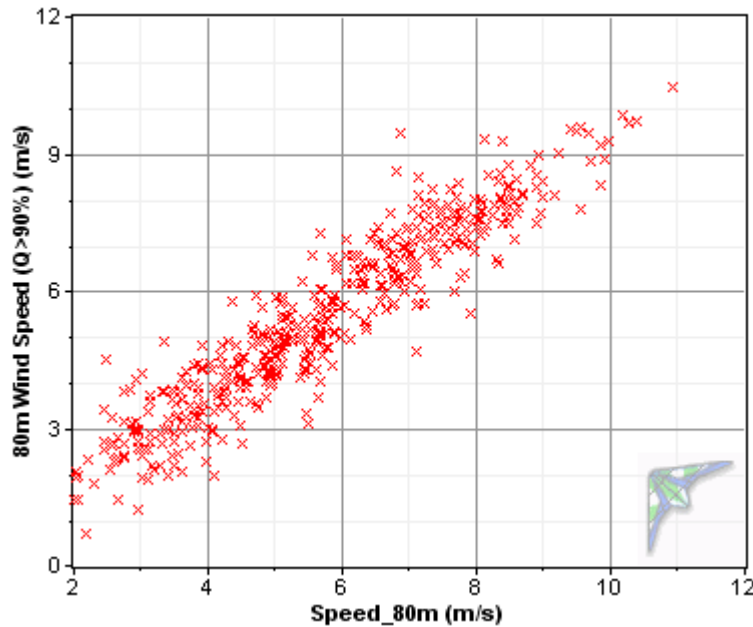
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- To define new climatologies using SODAR data, these should be correlated with mast data, acting as historical data
- Before performing correlation, SODAR data should be proved to be reliable as stand-alone wind measurements
- Therefore in Position I, being SODAR and Mast under similar exposure conditions (70 m distance), a comparison was carried out
- Filtering actions:
  - Minimum quality factor = 95%
  - Minimum vertical speed = -1.0 m/s (rain); Max = 5.0 m/s
  - Minimum cup anemometer speed = 2 m/s
  - Wind direction sector 45° aside from boom orientation of cup anemometers
  - Conversion of SODAR speed from vector average to scalar

# Comparison of SODAR and Mast measurements (1/2)

Number of points : 5,041  
Mean x value : 6.39 m/s  
Mean y value : 6.65 m/s

$\Delta = 0.26 \text{ m/s}$  (4%)



SODAR posiz. I

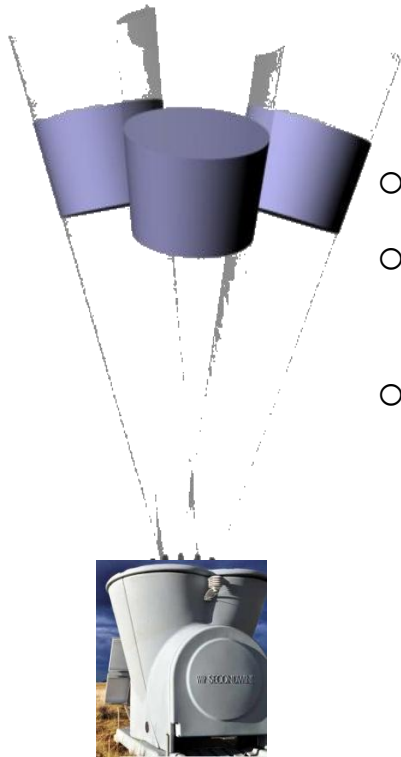
- The difference is considered too high to use **SODAR** device as stand-alone measurements, in this case



- Possible sources of the error:
  - Spatial variability
  - Anemometer error due to off-horizontal flow
  - SODAR error due to flow curvature

## Comparison of SODAR and Mast measurements (2/2)

- Further analysis on the inflow angle doesn't provide convincing evidence on cup sensor error due to off horizontal flow
- Flow curvature may be implied, because



- Beams tilt is  $11.4^\circ$
- Distance between beams is 32 m @ 80 m height
- Flow curvature could play a role

[Ferhat Bingol (Risø-PhD-52(EN)) ]

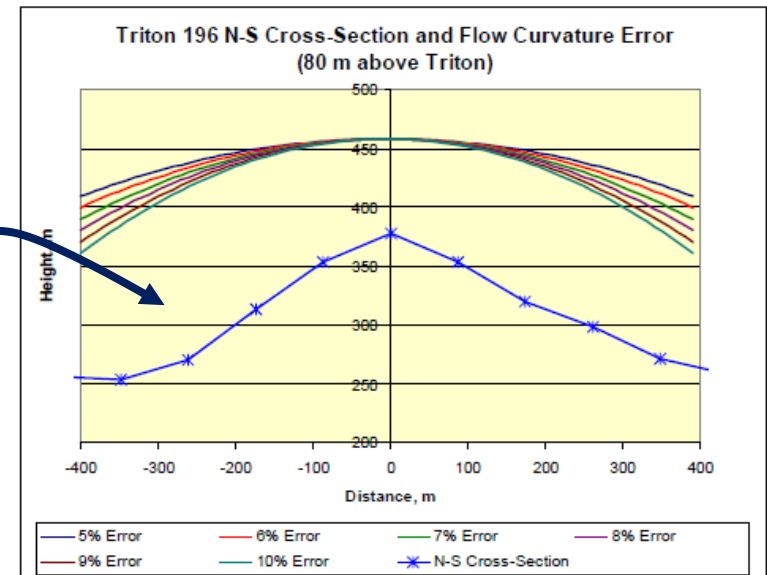


Figure 9: Triton 196 N-S Cross-Section and Flow Curvature

## Discussion

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- In a test case in complex terrain , an approach was shown to couple SODAR wind measurements with WindSim
- SODAR wind measurements in various site locations were used to gain insights on the wind shear, finally validating the CFD model and allowing the reduction of the related uncertainty
- The comparison of SODAR and Mast average wind speed showed a significant difference, which didn't allow to define new climatologies to be introduced in WindSim
- It was shown that flow curvature could play a role in the observed difference:  
**can WindSim correction tool help?**

## Contacts

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web: [www.studiorinnovabili.it](http://www.studiorinnovabili.it)

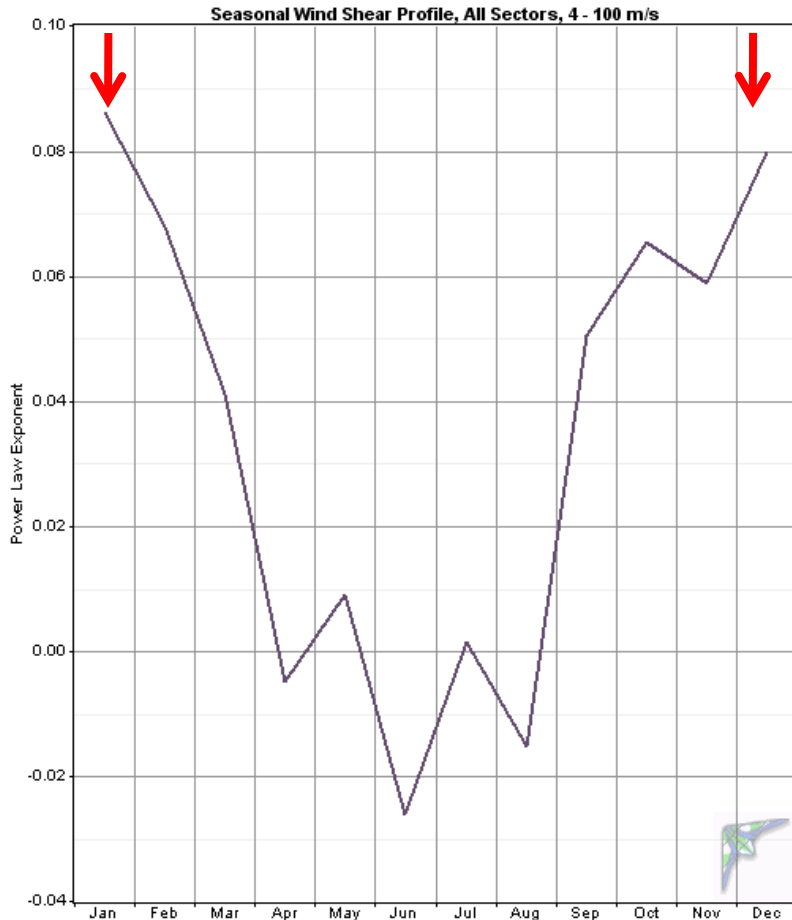
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web: [www.studiorinnovabili.it](http://www.studiorinnovabili.it)

# Appendix

## SODAR data – Position 1 – comparison of vertical profiles

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- seasonal variability of the wind shear @ 80 m Mast.

# Appendix

## Possible cup anemometer error due to off-horizontal flow

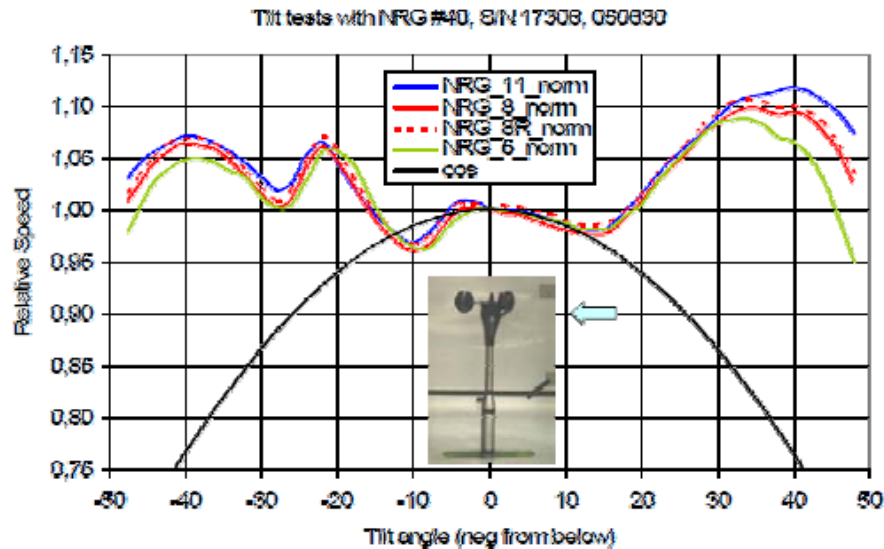
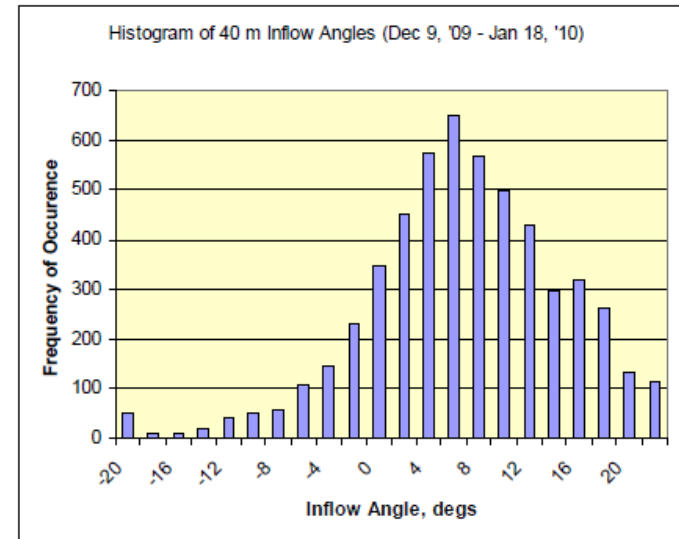


Figure 6: NRG Max 40 Error due to Off-Horizontal Flow



# Appendix

## Inflow angle

---

WTG	SECTOR											
	1	2	3	4	5	6	7	8	9	10	11	12
T-01	-2.4	-1.6	-4.1	-3.0	-1.2	0.4	2.2	2.2	3.7	3.3	1.5	0.0
T-02	-1.4	0.2	0.2	3.1	3.3	3.5	1.9	-0.5	-0.4	-1.9	-1.1	-1.3
T-03	-2.4	-1.5	0.7	3.7	4.4	4.0	3.1	1.4	0.3	-1.5	-3.6	-3.3
T-04	-1.4	-1.7	-1.9	0.5	2.0	4.9	5.2	4.8	1.4	1.1	-3.0	-2.1
T-05	-0.4	-1.3	-2.1	-2.0	-3.1	-0.4	1.0	3.3	4.1	2.6	1.6	1.6
T-06	2.6	2.6	0.8	-0.2	-3.0	-2.5	-2.1	-1.0	0.0	1.4	0.9	2.4
T-07	-0.8	-1.4	-1.4	-1.2	-1.0	1.4	2.7	0.7	2.9	2.2	0.7	0.2
T-08	3.5	3.6	1.8	1.0	-2.1	-3.2	-2.2	-4.8	-2.3	-1.0	1.3	2.8
T-09	-4.6	-4.8	-4.2	-0.6	2.6	5.7	6.2	5.4	3.9	2.1	-0.5	-3.8
T-10	-1.2	-0.9	-1.2	0.9	0.6	1.1	1.0	2.3	-0.6	-0.1	-0.6	-0.8
T-11	2.8	2.2	0.8	0.3	-1.4	-2.4	-3.1	-2.2	-1.8	0.5	1.4	3.2
T-12	1.2	1.5	0.3	-0.1	0.3	0.6	0.7	0.5	3.0	2.3	1.4	1.1
T-13	4.0	2.8	0.9	-0.4	-3.3	-3.8	-3.2	-0.9	1.9	3.8	3.9	5.1
T-14	9.6	8.7	5.7	1.1	-3.5	-7.8	-9.4	-6.7	-1.0	0.3	4.9	8.9
T-15	5.8	2.4	-1.0	-3.3	-8.1	-9.2	-6.8	-4.2	3.5	5.2	7.9	8.8