

Forest - added Turbulence:

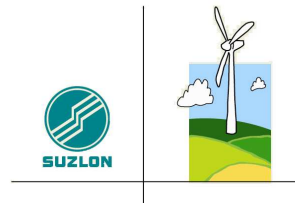
A parametric study on Turbulence
Intensity in and around forests

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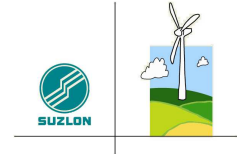
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Aim



Tool to estimate turbulence at different heights

Improve micro-siting when a forest is present

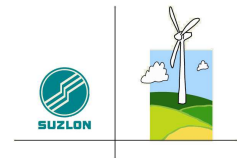
Minimize service and maintenance costs

Increase lifetime operation for WTGs

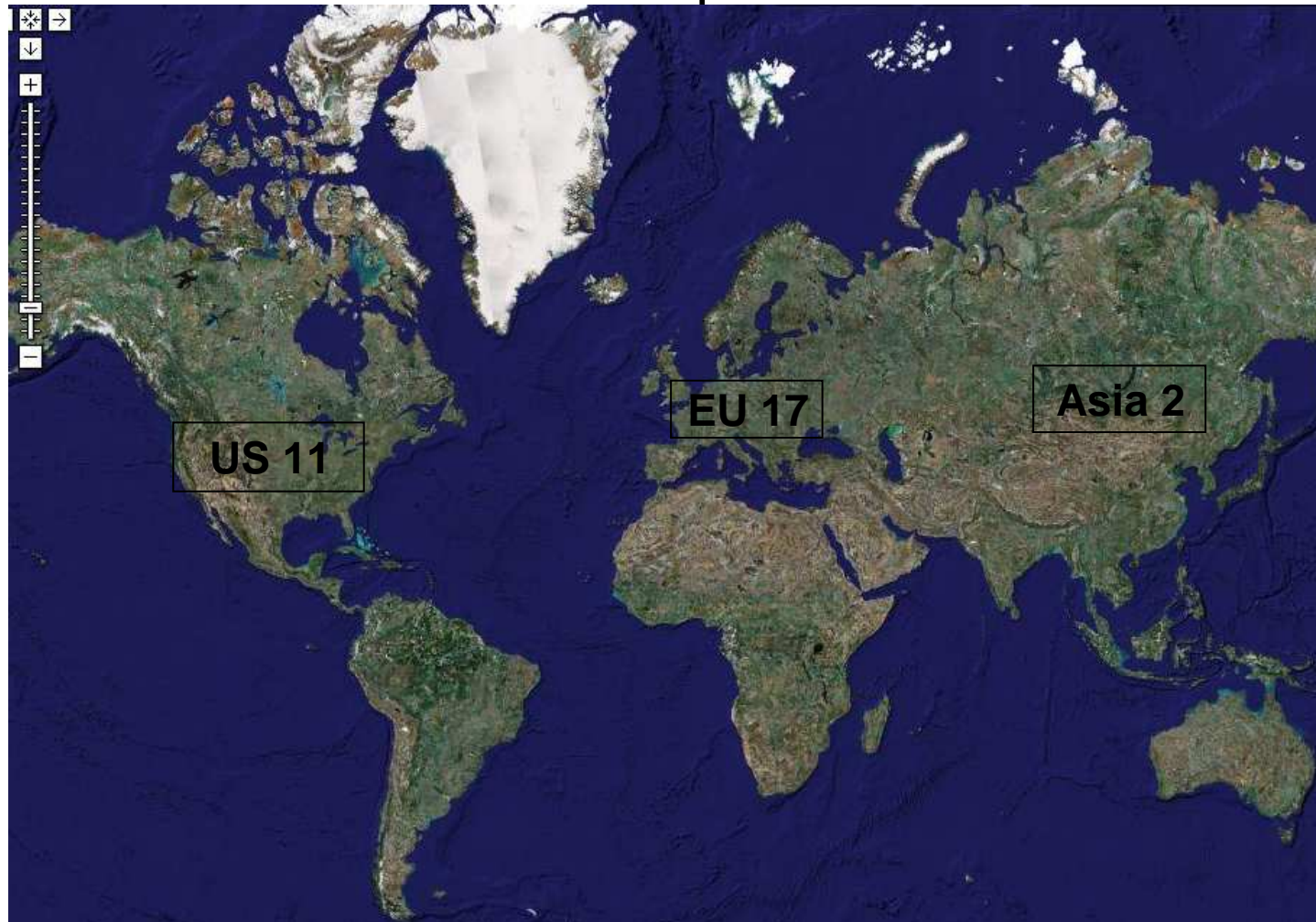
- Overview of added turbulence downstream from a forest
- Forest turbulence database
 - Data contained
 - Data treatment
- Results from the forest database
 - TI% as a function of wind speed
 - TI% as a function of height above forest
 - Ti% as a function of distance to forest edge
 - Results compared with wind tunnel tests
- Conclusions and future work.



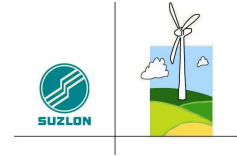
Forest turbulence database contents



- 30 forest sites from around the globe
- 83 different measurements points



Forest turbulence database



All sites in the database contain measurements with the following characteristics:

Measurement mast within 2000 meters of forest edge

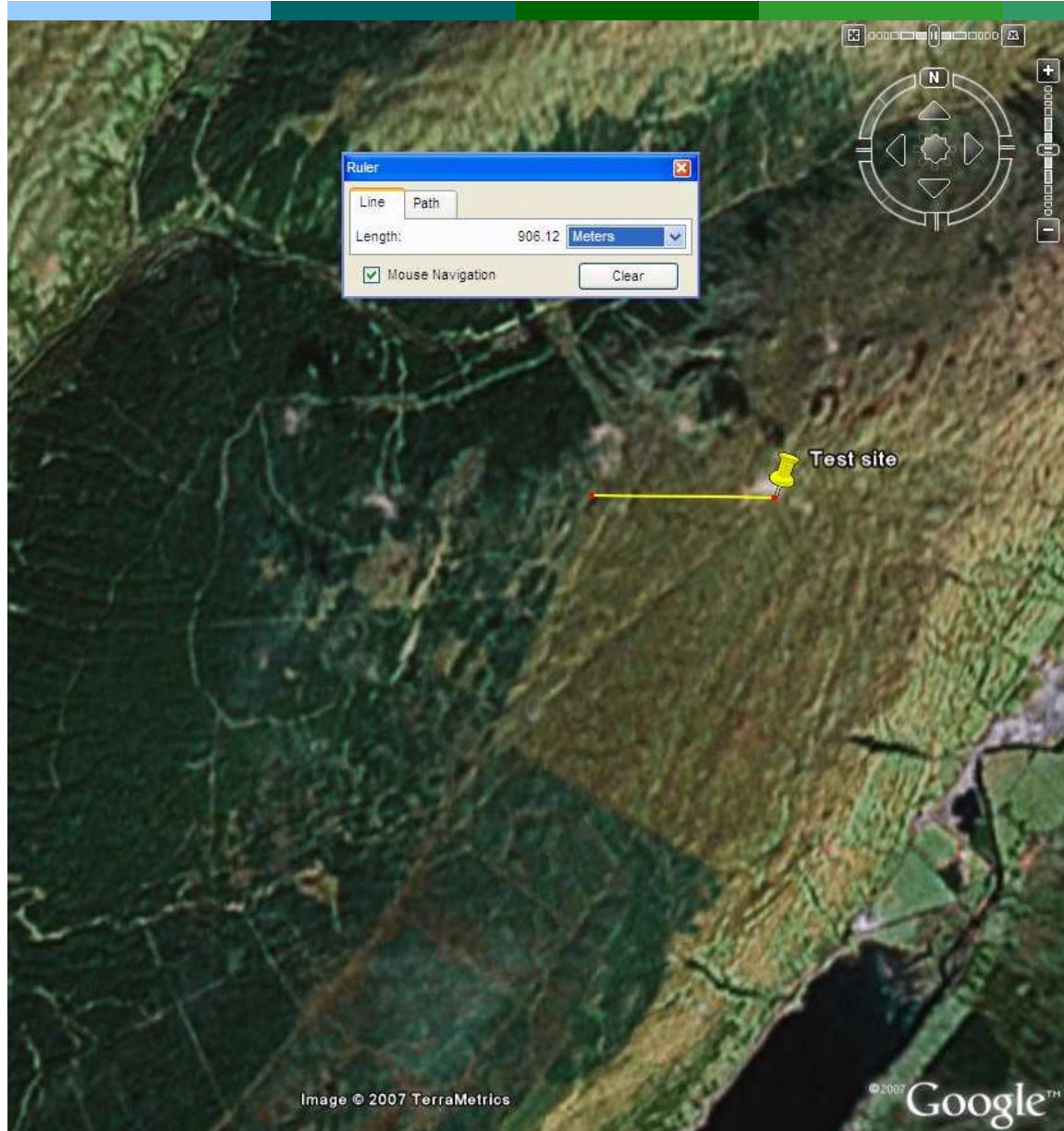
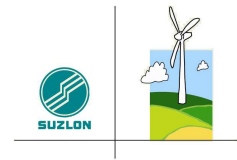
Forest larger than 1000 x 1000 meters

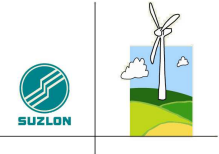
Measurement period minimum 1 year

Measurement height minimum 30 meter agl

Time series available as 10-minute averages

Indexing sites

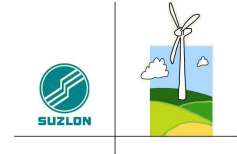




On-site ambient turbulence intensity is determined as follows:

- Average value for wind speeds above 10 m/s for 12 directional sectors
- Separate values for 1 m/s wind speed bins and 12 direction bins
- Indexed with distance to forest edge
- Indexed according to measurement height

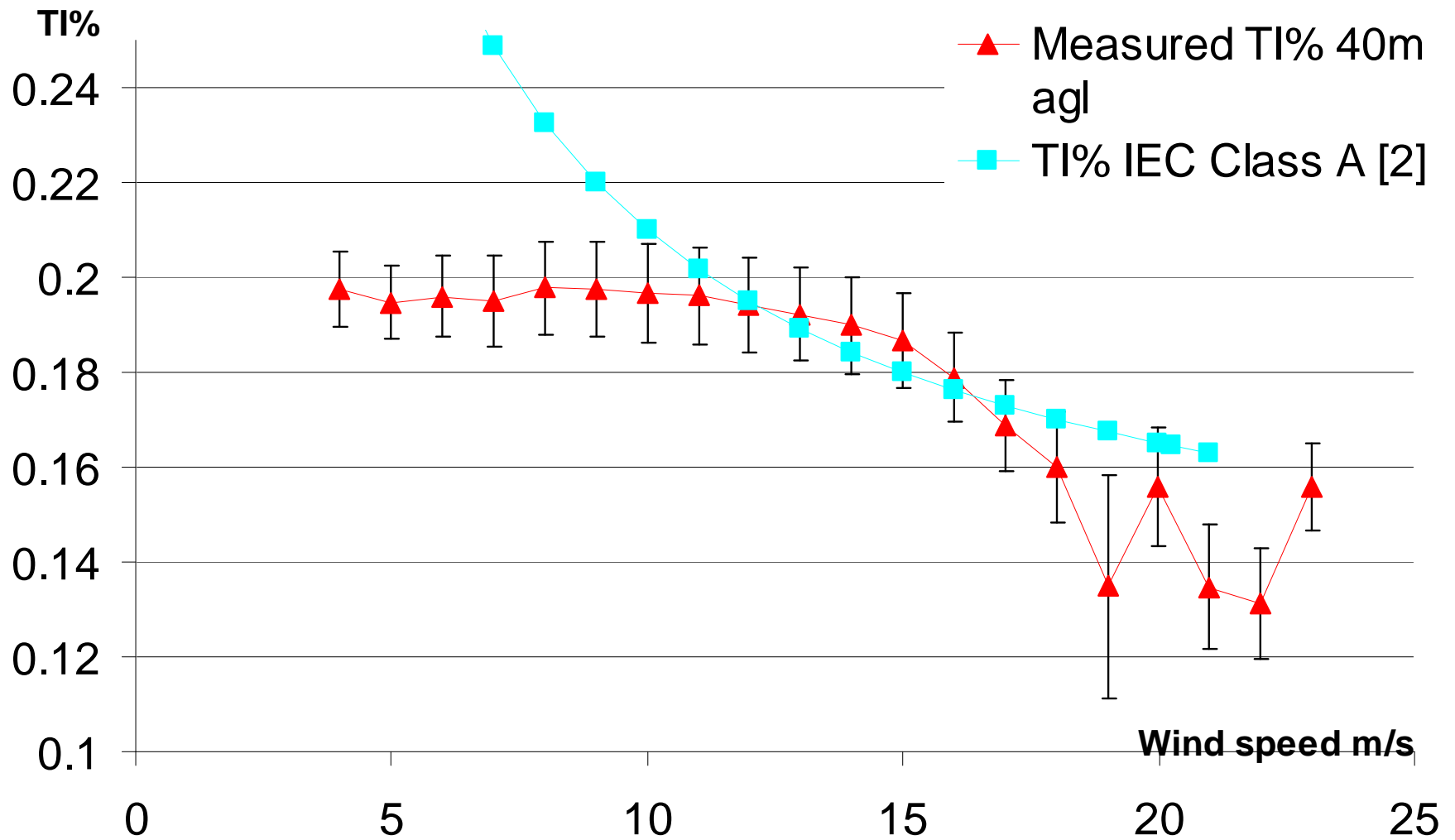
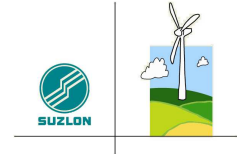
Results from the forest turbulence database



Results are averages of

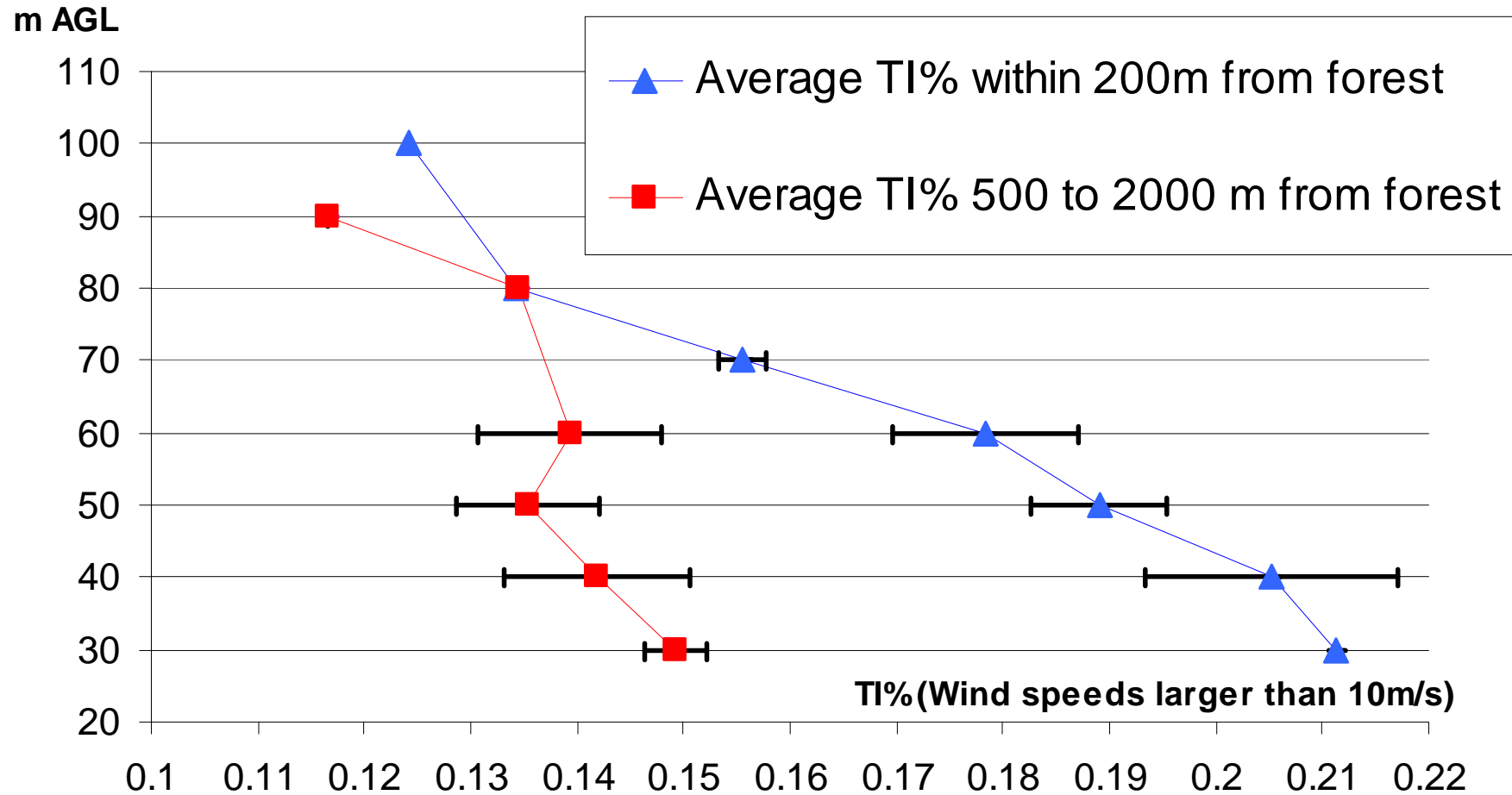
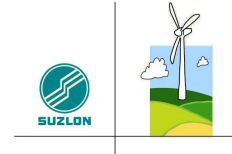
- different site specific conditions
- varying tree height, from 6 to 20m
- different forest types

Forest turbulence vs wind speed



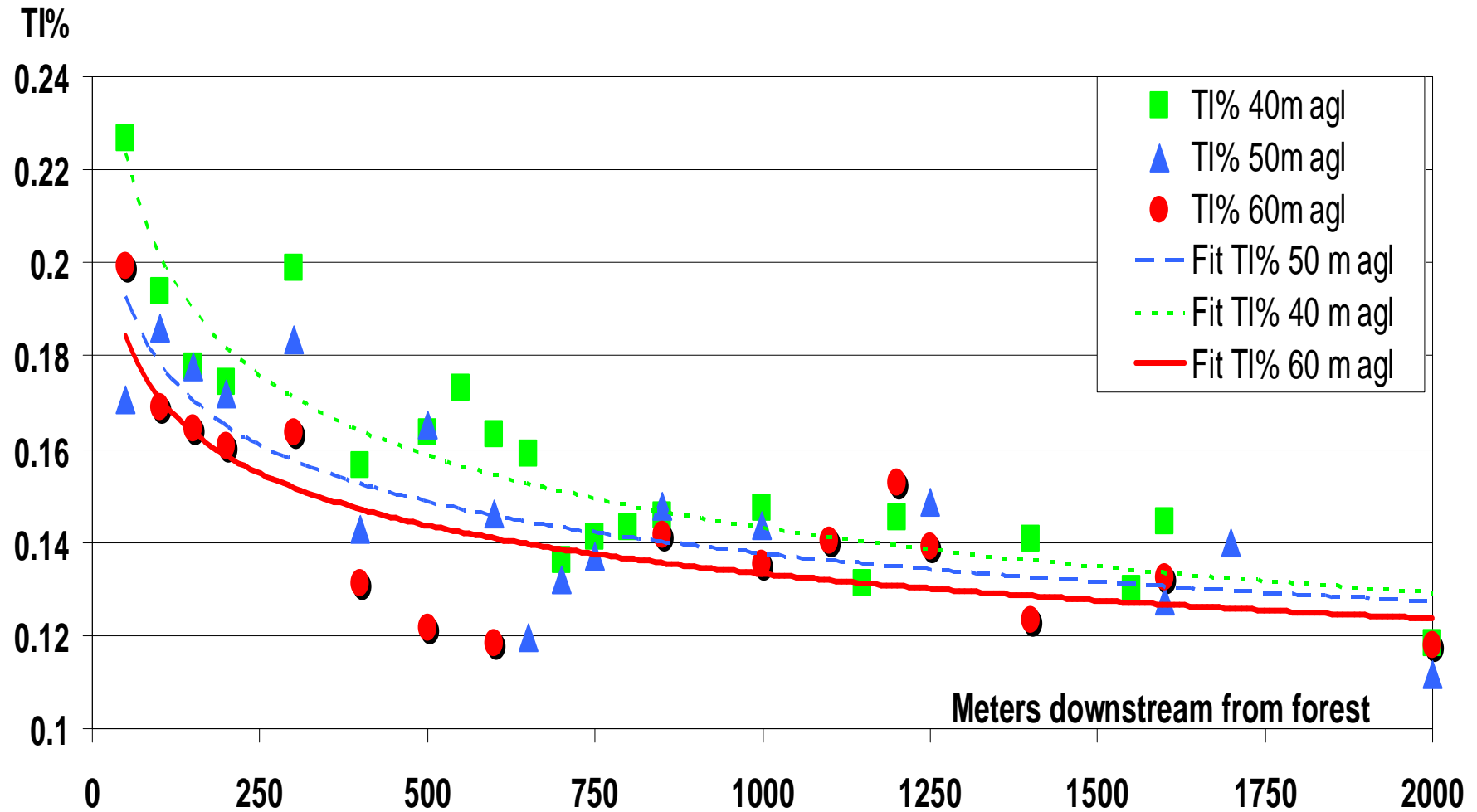
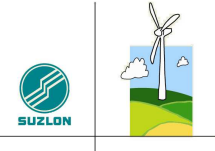
Y-error = standard error of the mean

Ambient turbulence as a function of height

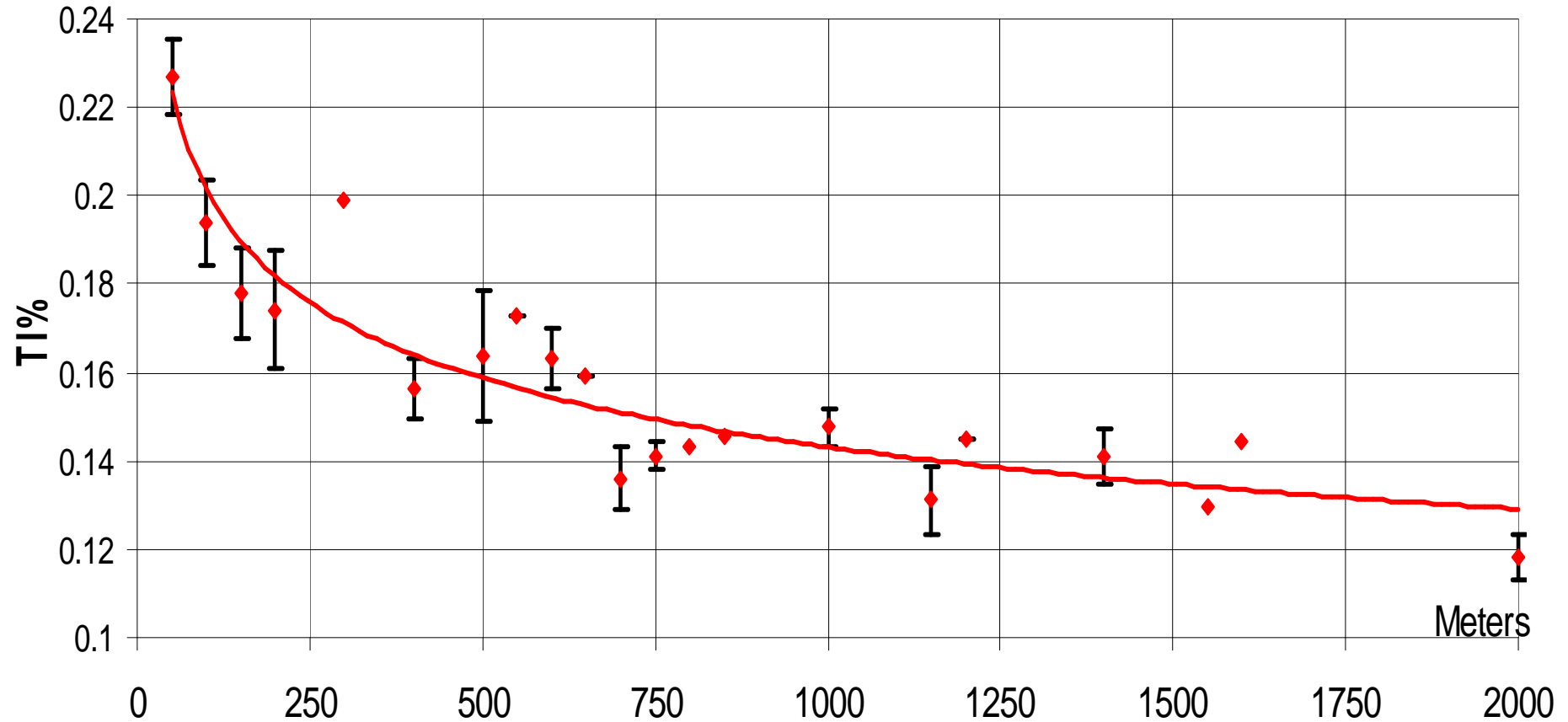
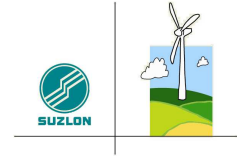


X-error = standard error of the mean

Average TI% from forest edge



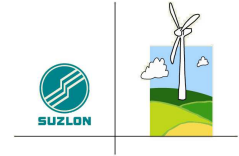
Average TI% from forest edge : 40 meter measurement height



y-error = Standard deviation of the mean

25-30% reduced turbulence 500 m downstream from forest edge

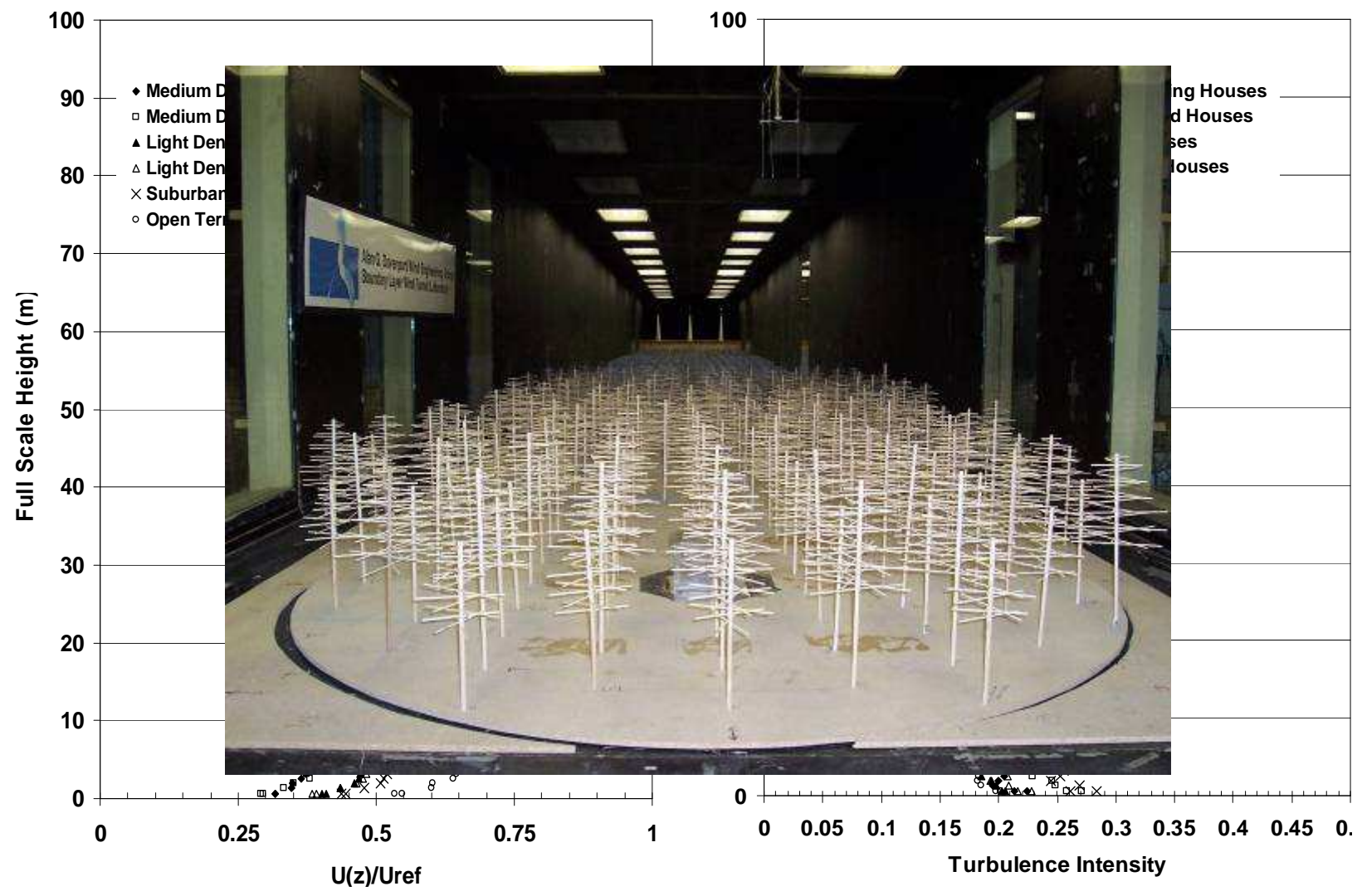
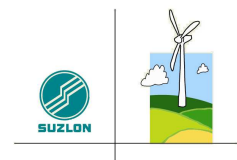
How does it match with theory



Difficult to compare with theory and other tests because

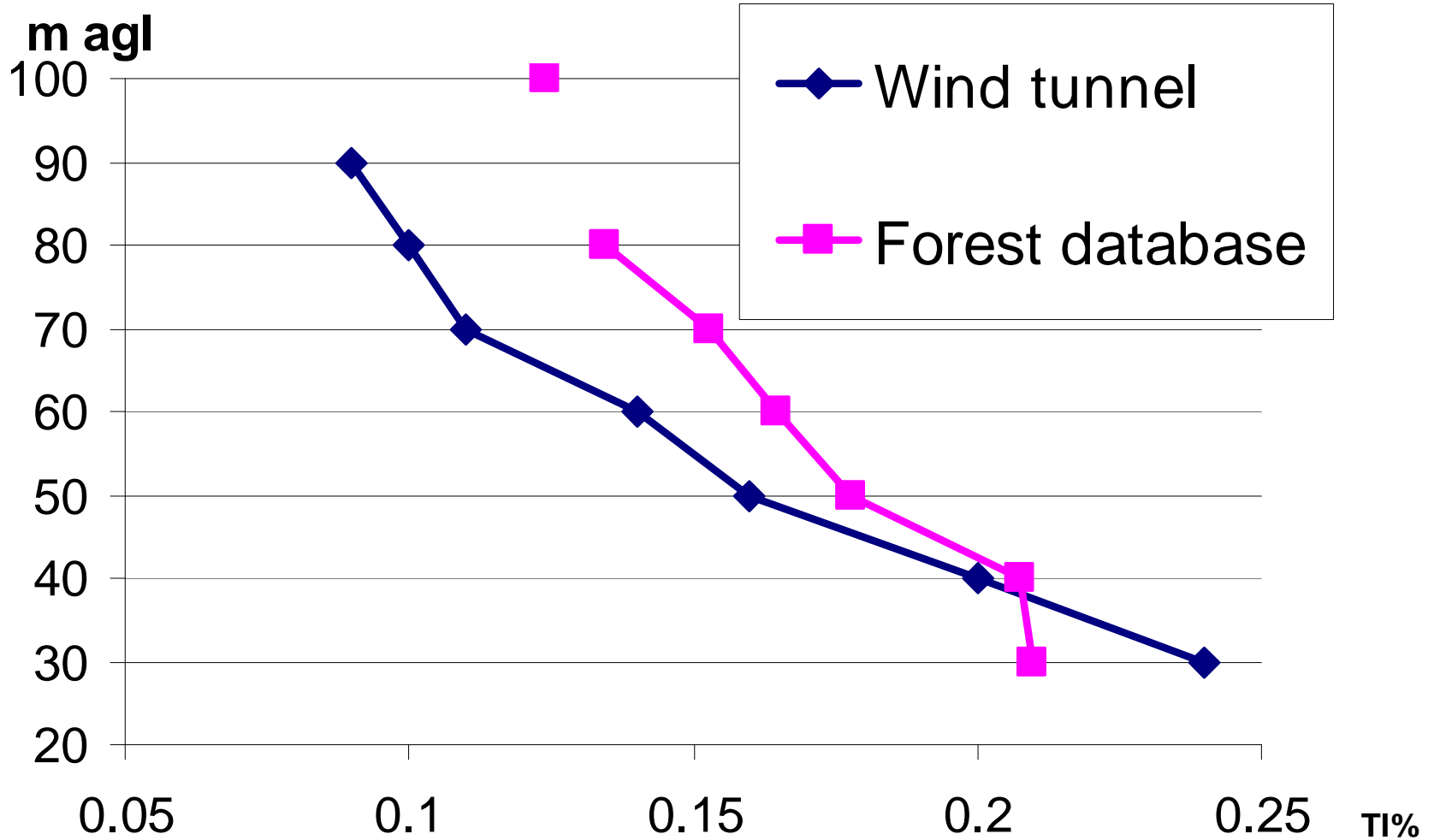
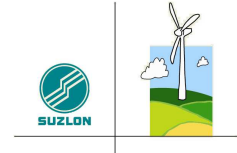
- Most theoretical studies are based on a single site or wind tunnel studies
- Results are averages of different forest types
- Individual site results vary up to 40% from the calculated average for all sites.

Wind tunnel test:



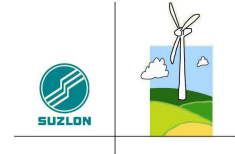
Wind profiles under different conditions.

Comparison with wind tunnel tests



Same trends, but the real world data have higher values than wind tunnel results

Comparison with Wasp Engineering

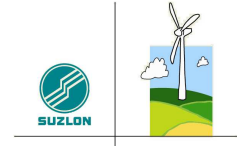


WAsP engineering test calculations.

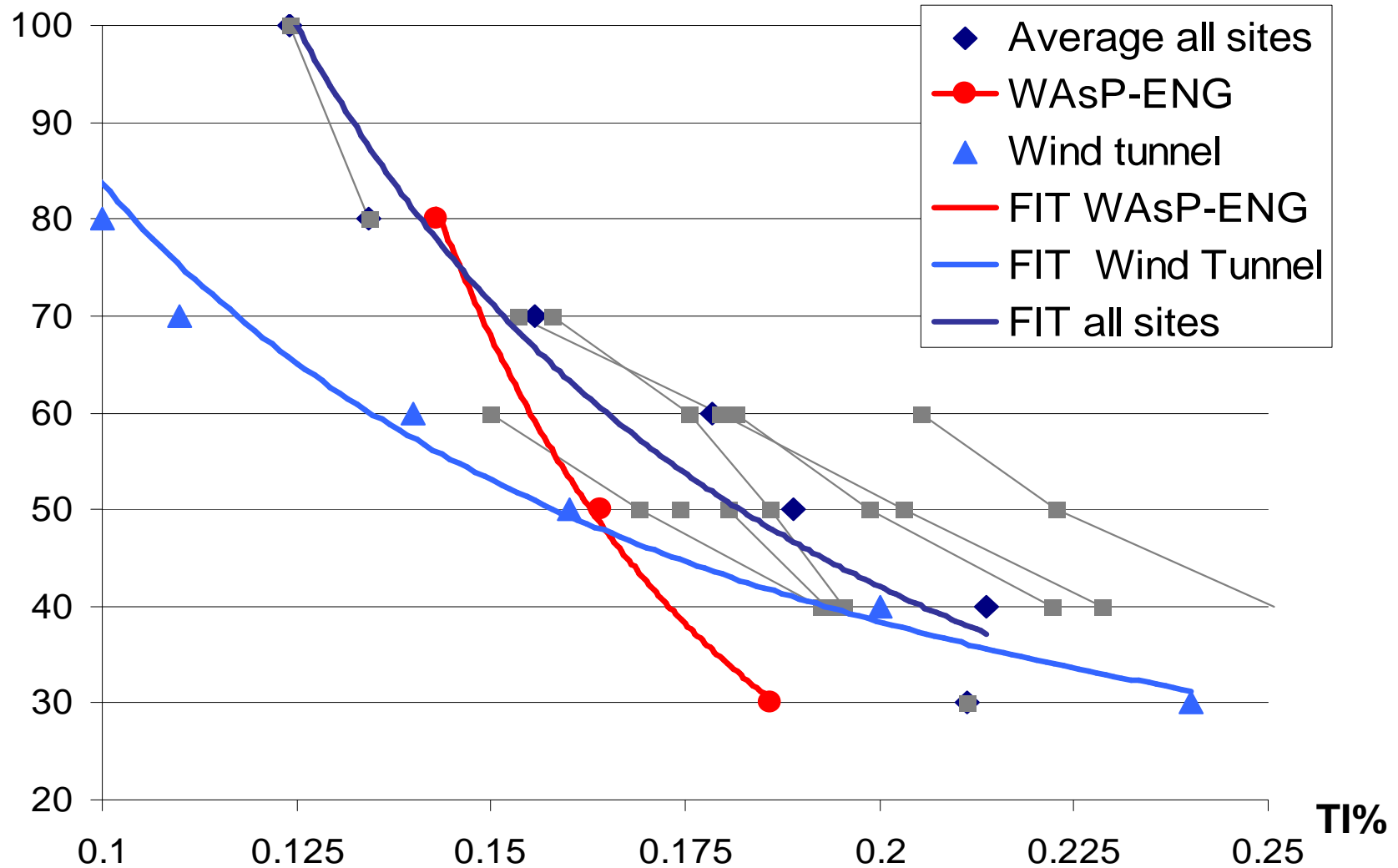
WAsP engineering calculation for a site in the middle of a forest. Roughness class of 4.0 used for the forest.

WAsP-ENG	TI database	Measured	M agl
18.6 %	23.0 %	21.1 %	30 m
16.4 %	18.6 %	17.4 %	50 m
14.3 %	14.5 %	<u>???</u>	80 m

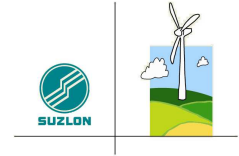
Turbulence as a function of height: Comparison to WAsP-ENG and wind tunnel test



M agl.



Conclusion - Future Work

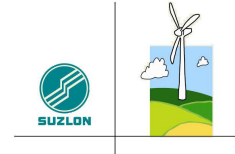


- Its strongly recommended to measure on-site at expected hub height.
- Above 5 times the tree height rapidly decrease of TI
- First 500m behind forest most critical
- Wasp Engineering seems to be conservative compared to measurements.
- Continue to expand database
- Develop equation for reduced turbulence as a function of height and distance to a forest edge
- Compare equation with models such as WAsP Engineering or more advanced CFD programs

New data ?

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<http://www.undeerc.org/wind/>

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