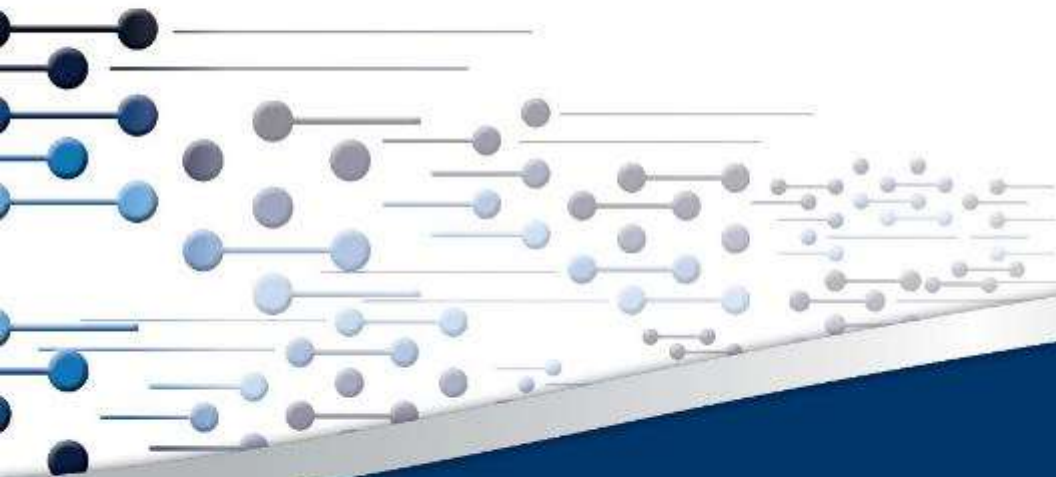


# Benchmarking commercial microscale modelling codes

## CSIR Energy Centre

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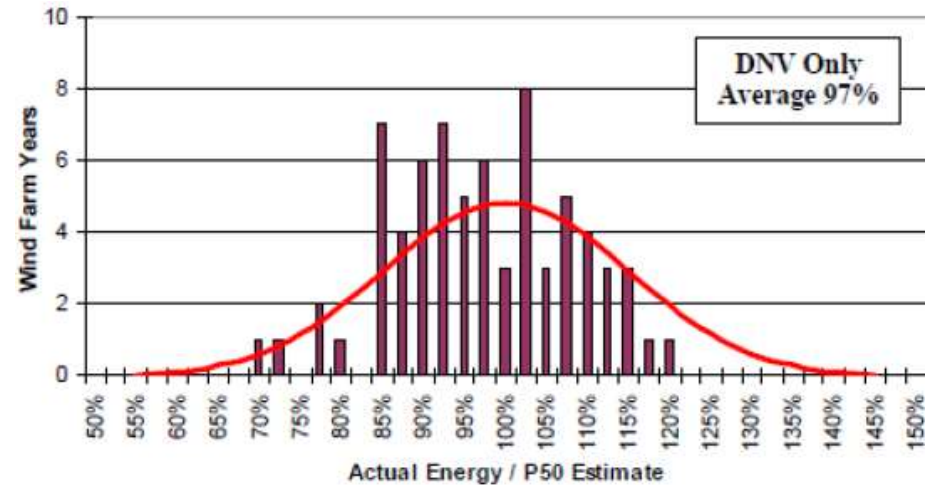
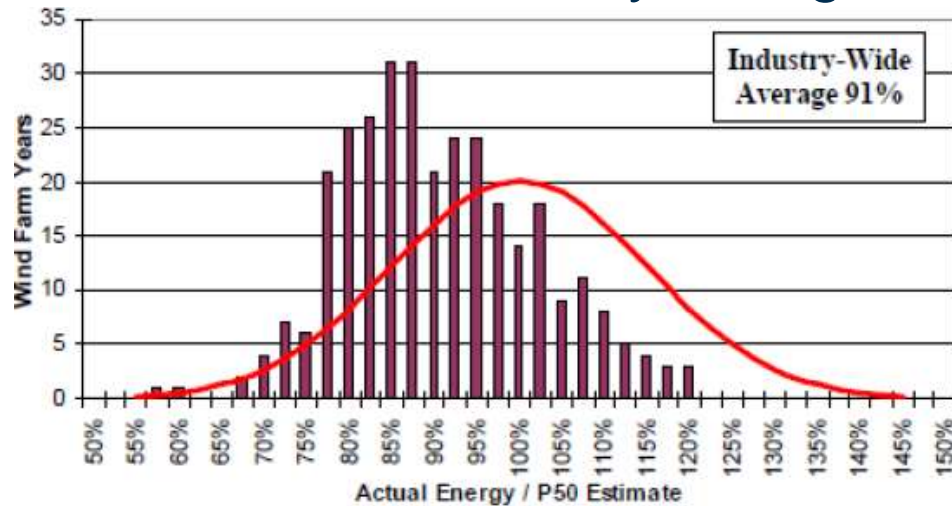
- **Why benchmarking microscale codes?**
- **Benchmarking setup – 2 codes**
- **Modelling: Pre-processing**
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# Why benchmarking microscale codes?

- Wind farms not yielding the pre-construction AEP

Which and what methods were applied by whom?

Normal or complex sites?

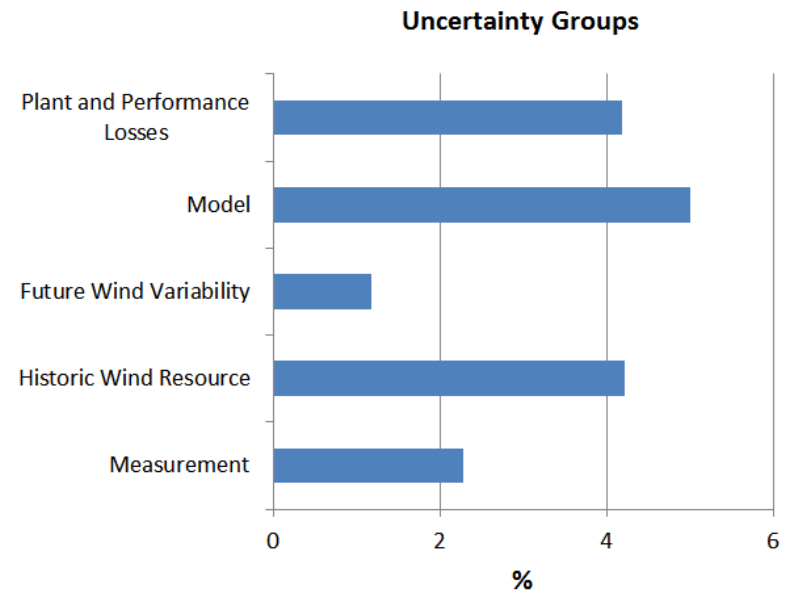
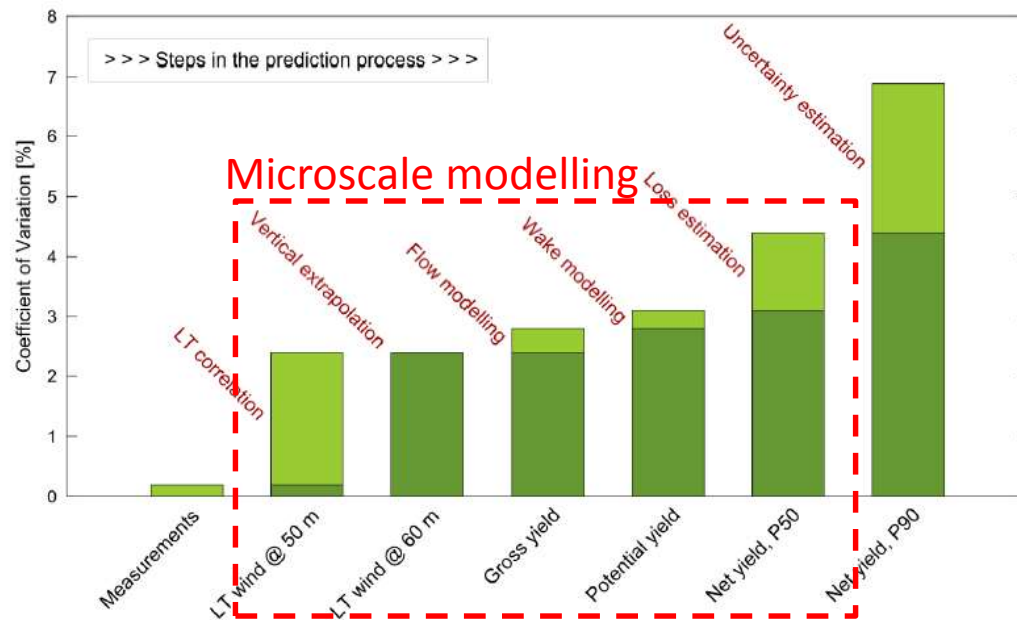


Were the assumptions conservative enough?

Old/new wind turbine mix?

# Why benchmarking microscale codes?

- AEP prediction variance and uncertainty largest in the microscale modelling of wind and wind farm



Source: Mortensen, N.G., Jørgensen, H.E. 2013. Comparative Resource and Energy Yield Assessment Procedures (CREYAP) Pt. II. URL: [www.ewea.org/events/workshops/wp-content/uploads/2013/06/EWEA-RA2013-Dublin-5-5-Niels-G-Mortensen-DTU-Wind-Energy.pdf](http://www.ewea.org/events/workshops/wp-content/uploads/2013/06/EWEA-RA2013-Dublin-5-5-Niels-G-Mortensen-DTU-Wind-Energy.pdf)

# Why benchmarking microscale codes?

- Ultimately, lowering inaccuracies and uncertainties lead to higher project profits  
e.g. 10 % increase in AEP → 20M Euro profit increase over project lifetime



Source: Gravidahl, A.R. 2014 Wind modelling – The Danish way or Norwegian way? Presented at the NORWEA Seminar. March. URL: [www.norwea.no/Admin/Public/Download.aspx?file=Files%2FFiler%2FArrangemententer%2FMulticonsult+WindSim+Norwea+18.03.14%2F140319\\_WindSim\\_Multiconsult\\_NORWEA\\_ARG\\_Wind\\_farm\\_layout\\_design.pdf](http://www.norwea.no/Admin/Public/Download.aspx?file=Files%2FFiler%2FArrangemententer%2FMulticonsult+WindSim+Norwea+18.03.14%2F140319_WindSim_Multiconsult_NORWEA_ARG_Wind_farm_layout_design.pdf)

# Benchmarking setup

- A number of microscale modelling codes considered  
e.g. WAsP, Meteodyn, OFWind, WindPro, WindFarmer, etc.
- Codes – different flavors of full a CFD code  
i.e. linear or non-linear derivatives
- First approach budgeted code comparison – 2 codes  
a linear code and a non-linear code were selected
- Goal: flow modelling capability comparison and expose  
data shortfalls

# Benchmarking setup

- Comparison involves a normal and a complex sites

WASA sites – WM07 (normal) and WM11 (complex)



# Benchmarking setup

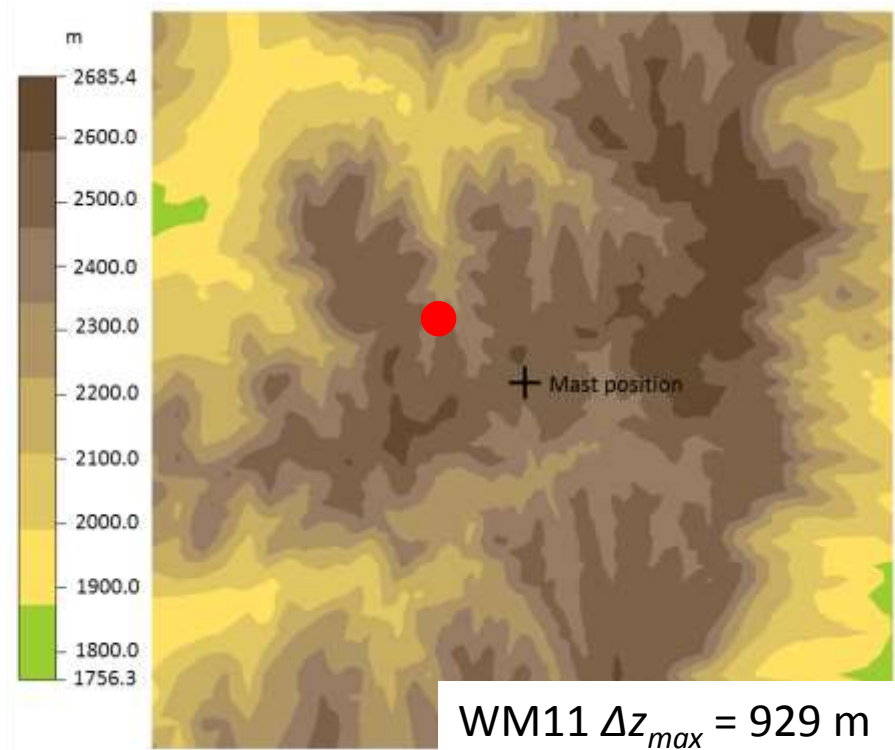
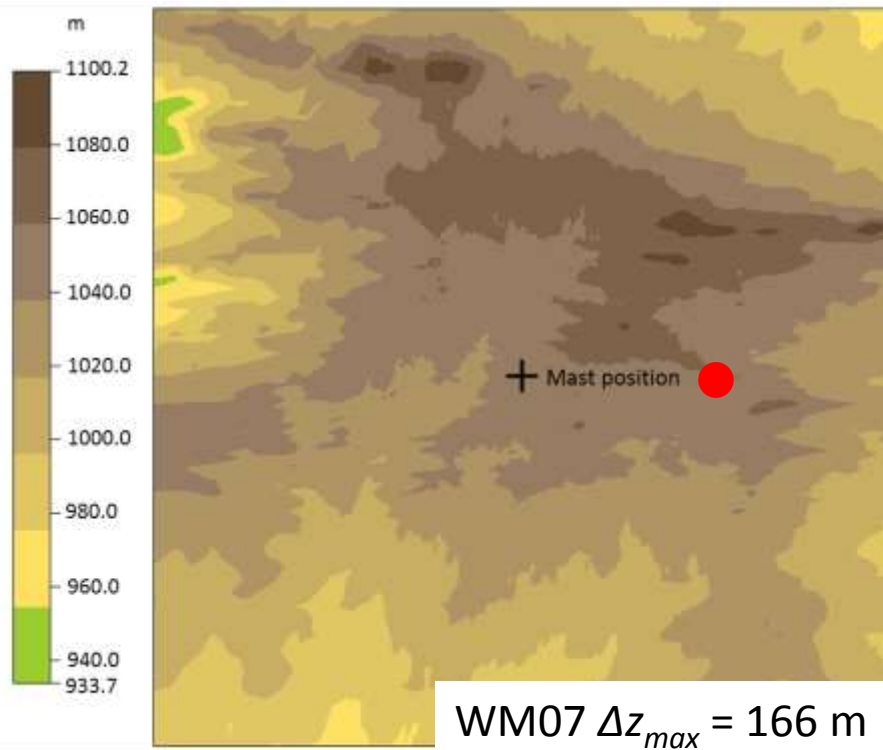
- **Basis for comparison**
  - quality observed meteorological data
  - reasonable terrain data
  - code input data format compatible
- **Comparison limitations**
  - flow calculations only based on observed climate data → no re-analyzed data
  - comparison involves a single point of measurement → not ideal
  - a single turbine was selected → no wake modelling capabilities analyzed
- **Measures for comparison**
  - wind resource map – spatial distribution
  - wind speed profiles – vertical distribution
  - gross AEP involving a dummy 2 MW wind turbine



# Modelling: Pre-processing

- Terrain data - topography

20 x 20 km topographical data (SMRT 1-arcsecond) – 5 m vertical resolution

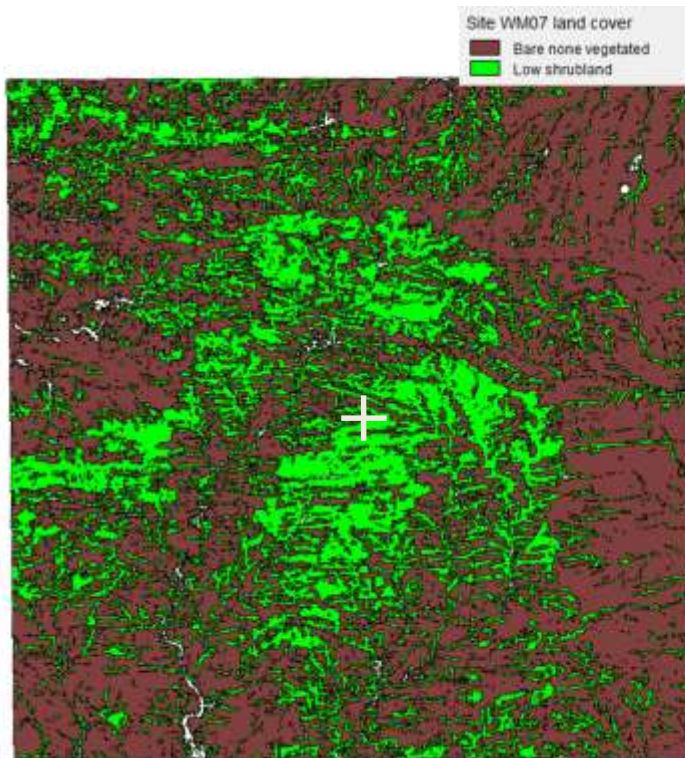


● indicates wind turbine location

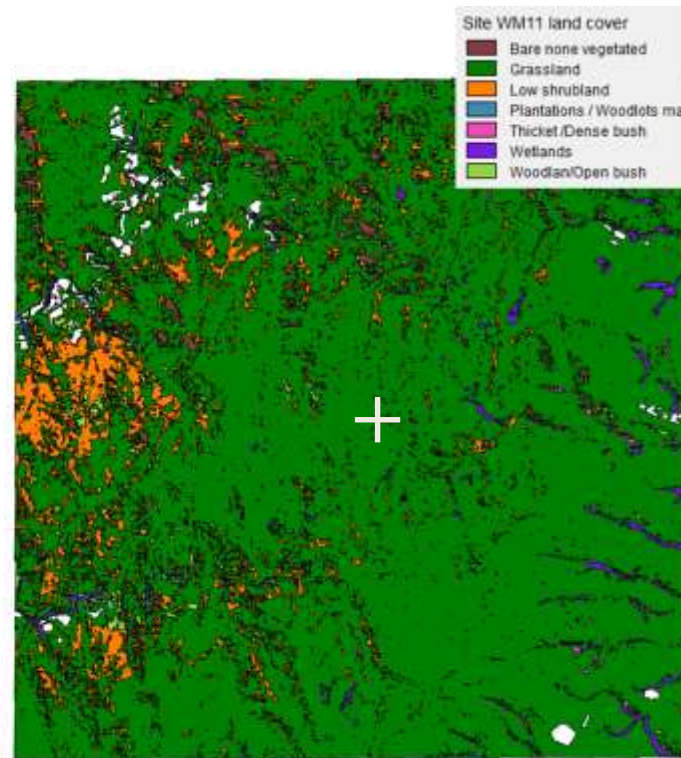
# Modelling: Pre-processing

- Terrain data - orography

2014 South African National Land-Cover Dataset - 30 m spatial resolution



$z_0 = 0.03$  to  $0.1$  m  $\rightarrow$   $0.06$  m



$z_0 = 0.05$  to  $0.1$  m  $\rightarrow$   $0.05$  m

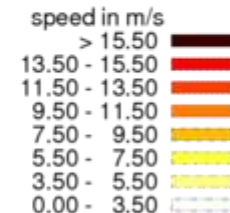
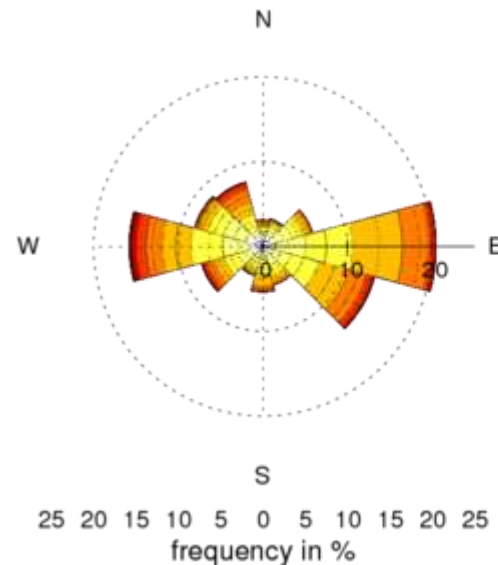
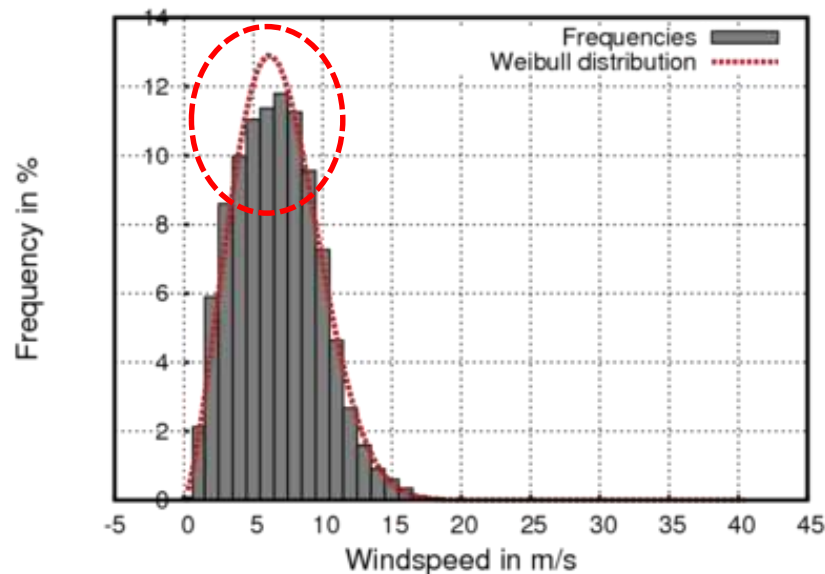
# Modelling: Pre-processing

- Climatology – local wind climate – WM07

derived from 2016 10-minute average observations ( $u$ ,  $u^o$ ,  $\Theta$ ,  $\Delta\Theta$ ,  $\omega$ ,  $p$ )  
wind speeds measured at 10 m, 20 m, 40 m, 60 m, and 62 m a.g.l

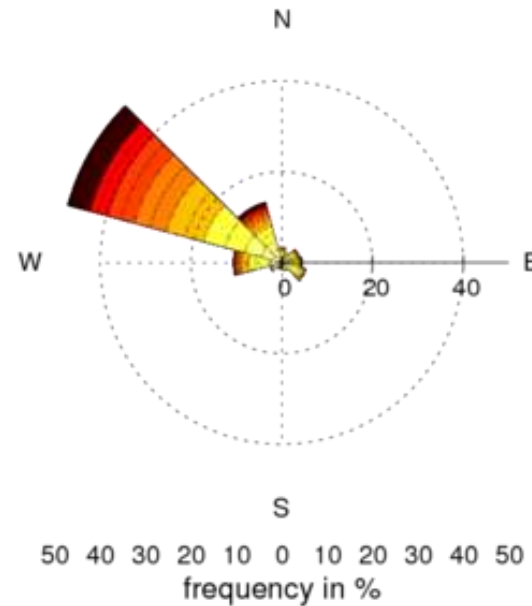
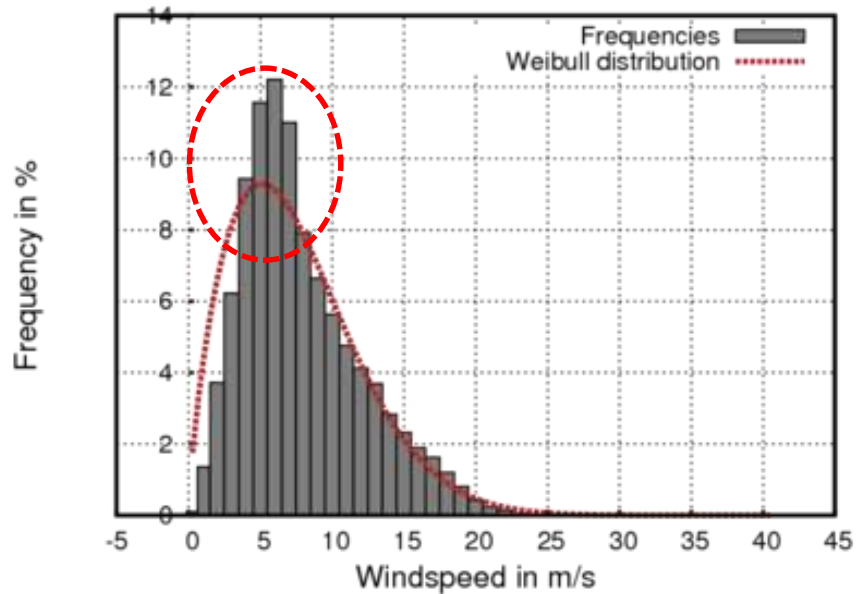
Weibull parameters at 60 m a.g.l –  $k = 2.43$ ,  $A = 7.7$  m/s,  $u_{avg} = 6.7$  m/s

Note:  $\Delta F \sim 1\%$



# Modelling: Pre-processing

- Climatology – local wind climate – WM11  
Weibull parameters at 60 m a.g.l –  $k = 1.72$ ,  $A = 8.5$  m/s,  $u_{avg} = 7.9$  m/s  
Note:  $\Delta F \sim 3\%$



# Modelling: Pre-processing

- Climatology – atmospheric stability

Atmospheric stability (cycles) involves the vertical movement of air pockets

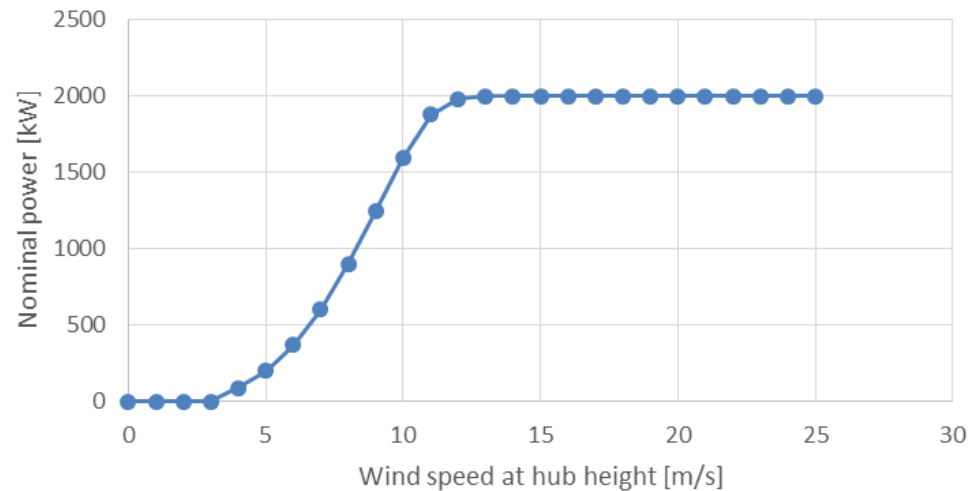
Stable, neutral or unstable conditions alters wind profile shape

Ideally more unstable conditions preferred – low wind shear across rotor area

	Unstable [ELR < -10 °C/km]	Conditional stability [-10 °C/km < ELR < -6 °C/km]	Neutral [ELR ≈ -10 °C/km or ELR ≈ -6 °C/km]	Stable [ELR > -6 °C/km]
WM07	48.2	1.5 (D), 9.9 (W)	0.1	40.3
WM11	32.3	1.8 (D), 12.1 (W)	0.1	53.5

# Modelling: Pre-processing

- Dummy 2 MW wind turbine model  
Horizontal axis machine with pitch regulated rotor  
80 m hub height and 75 m rotor diameter

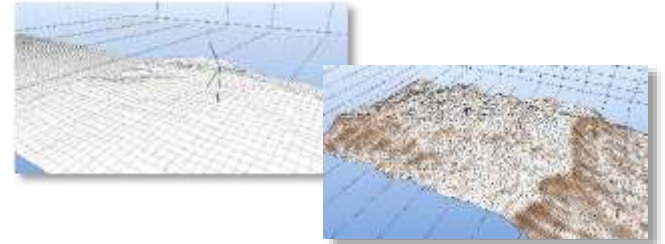


<b>u</b> [m/s]	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15 to 25
<b>P</b> [kW]	0	0	0	0	87	201	371	601	901	1243	1591	1876	1979	1999	2000	2000

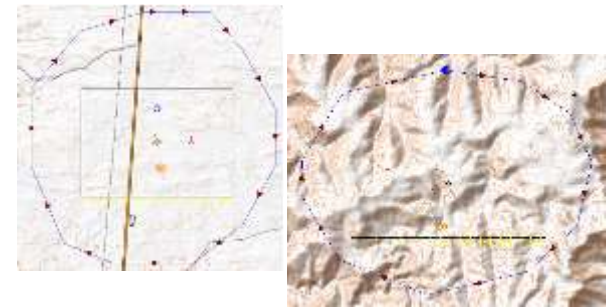
# Modelling: Pre-processing

- Linearized code setup sequence

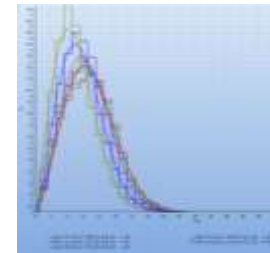
Topographical data → *Elevation Grid Data Object*



Orographic data → *Line Data Object (polygons)*



Climate data → *Meteo-Object*



Wind turbine data → *WTG Object*



# Modelling: Pre-processing

- Non-linearized code setup sequence

Topographical and orographic data → *Terrain module*



\*meshing

Generate wind field → *Wind Field Module*

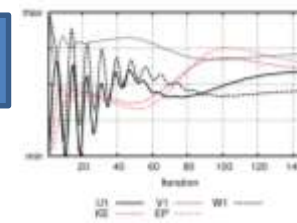
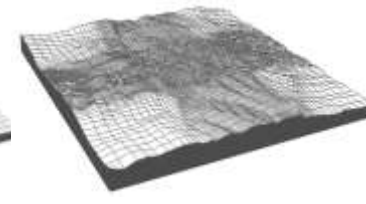
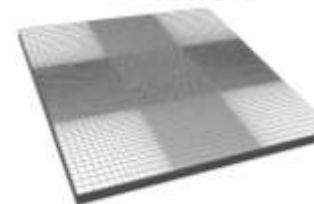
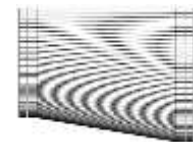
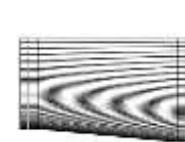


\*grid independence

Climate data → *Climatology Object*

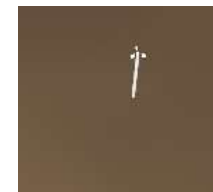


Wind turbine data → *Wind Turbine Object*



U1\_Max = 2.890E+00  
U1\_Min = -0.000E+00  
V1\_Max = -0.000E+00  
V1\_Min = 2.000E+01  
W1\_Max = 6.000E+01  
W1\_Min = 7.000E+01  
KE\_Max = 3.000E+00  
KE\_Min = 1.000E+01  
EP\_Max = 3.000E+01  
EP\_Min = 1.000E+02

Opt: max, global  
X\_pos = 60075.0  
Y\_pos = -349922.0





# Modelling: Solving

- Linearized code

no initialisation

solves 2D wind fields (vertical, horizontal) for 12 wind direction sectors

“turbulence” calculated using analytical functions

atmospheric stability – heat flux value

wind resource mapping - the *Resource* module

wind statistics (wind profile) – *STATGEN* module

wind turbine AEP - *Park* module

solved on PC - Intel i7-6600U processor @ 2.6 GHz, 16.0 GB RAM

total time to solutions less than 1 minute

# Modelling: Solving

- Non-linearized code - initial conditions applied

	Boundary layer height	Wind speed at boundary layer height	Top surface boundary	Side boundaries
WM07	800 m	10 m/s	No-friction wall	Velocity profiles
WM11	500 m		Fixed pressure	

	Temperature equation	Ref. temperature	Ref. height	Wind speed at ref. height	M-O length
WM07	Initialised from M-O length	289 K	60 m	6.69 m/s	-20
WM11		281 K		7.87 m/s	290

- Solving

grid independence results: WM07:  $10^6$  cells and WM11:  $4 \cdot 10^6$  cells

solves 3D wind fields (12 sectors) – CFD capability – PHOENICS code

turbulence calculated using 2-eq. Reynolds averaged k- $\epsilon$  model

solved on PC - Intel i7-6600U processor @ 2.6 GHz, 8.0 GB RAM

total time to solutions - 9 h (WM07) and 16 h (WM11)

# Modelling: Post-processing

- Per code post-processing modules or objects applied in extracting comparison measure figures

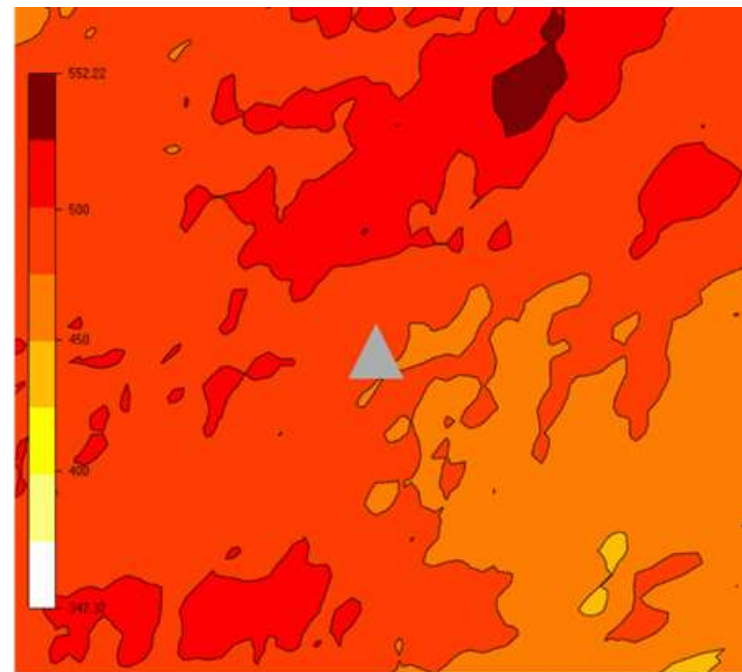
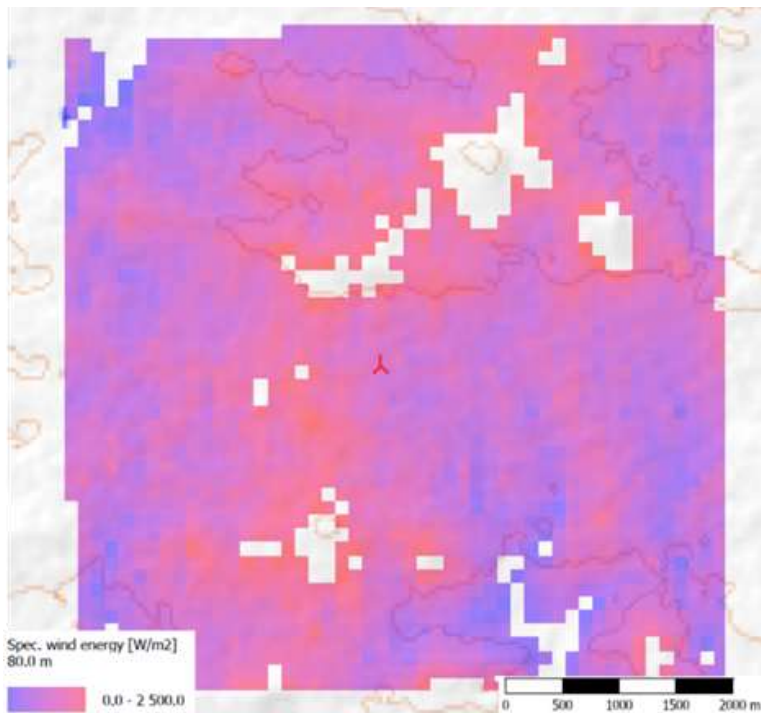
Measure	Linear	Non-linear
Wind resource map [W/m <sup>2</sup> ] @ 80 m a.g.l	<i>Resource</i>	<i>Results and Wind Resources</i>
Wind profiles [m/s] in prevailing wind direction	<i>STATGEN</i>	<i>Results and Energy</i>
Gross AEP [MWh/a] specific to 2 MW dummy	<i>Park</i>	<i>Results and Energy</i>

# Results

- Wind resource map –  $\text{W/m}^2$  @ 80 m a.g.l

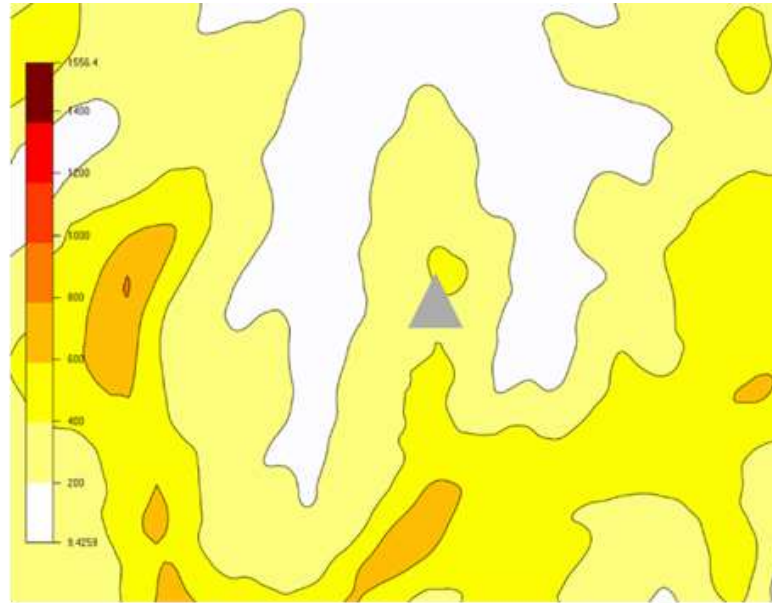
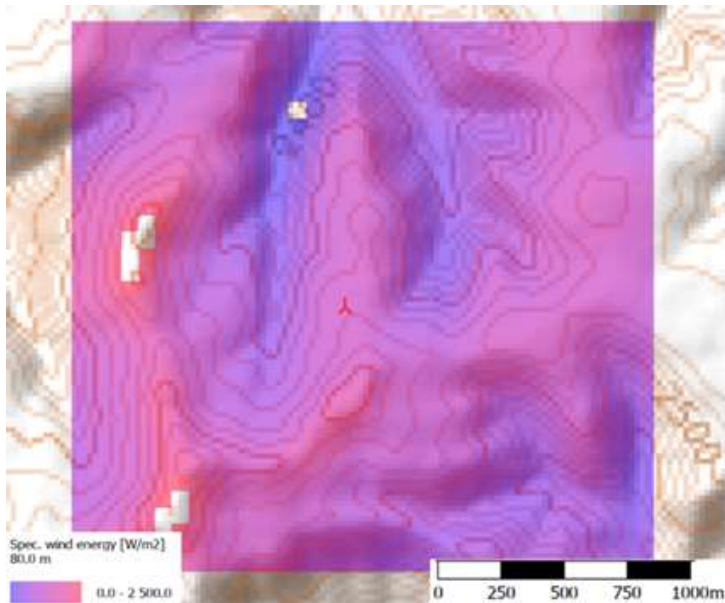
Visual comparison – pattern and value range

WM07



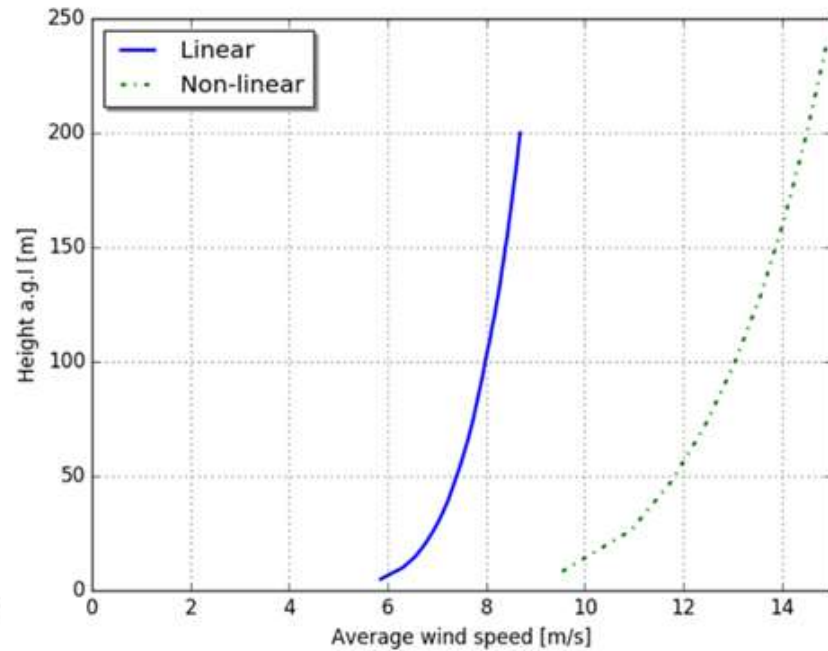
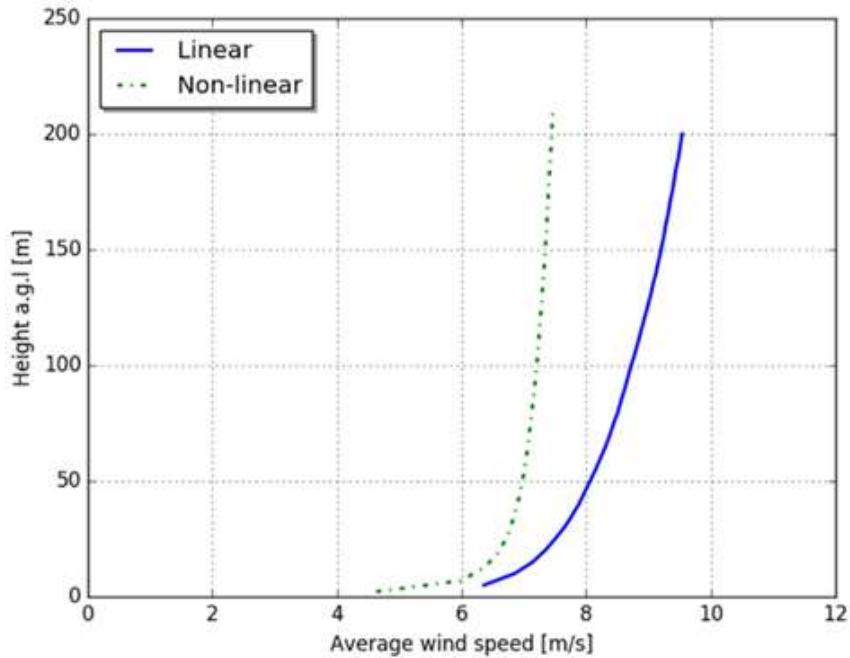
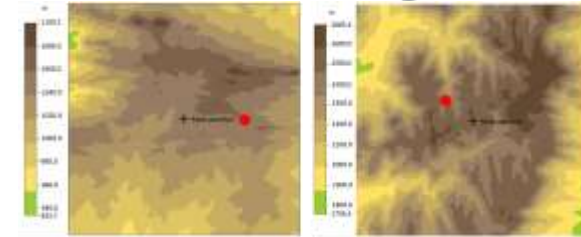
# Results

WM11



# Results

- Wind profiles – prevailing wind direction profile shapes indicates different stability conditions shear velocity offset not understood



# Results

- Gross AEP – 2 MW wind turbine (hub: 80 m Ø 75 m)

	Linearized [MWh/a]	Non-Linearized [MWh/a]	% Difference
WM07	6383	6657	4.1
WM11	6658	5978	10.2

# Conclusion

- Discrepancies in microscale modelling results

NOTE: comparisons are not final nor complete – work in progress

smallest AEP variation in results for normal site – WM07

non-linear model computations take orders longer

complex site wind profile mismatch not inline with what is expected

perhaps atmospheric stability conditions not correctly specified in linear model

comparison using one observed dataset (location) not ideal

the affect of upwind topographic features (Drakensberg) not included



# Future work

- Code comparison study will continue
- Aspects that will be investigated / introduced
  - multi-mast datasets incorporated
  - adapted re-analysed long-term data will be included
  - orographic model modified – SA surface roughness map
  - obstacles near model boundaries
  - correct specification of atmospheric conditions in linear codes

Glimpse of possible future – measurement driven

LiDAR measurement >>> machine learned models >>> adaption by AI

**Thank you**



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