Benchmarking commercial microscale modelling codes

CSIR Energy Centre

WindAC Africa 14-15 November 2017
Cape Town, South Africa

CSIR
our future through science

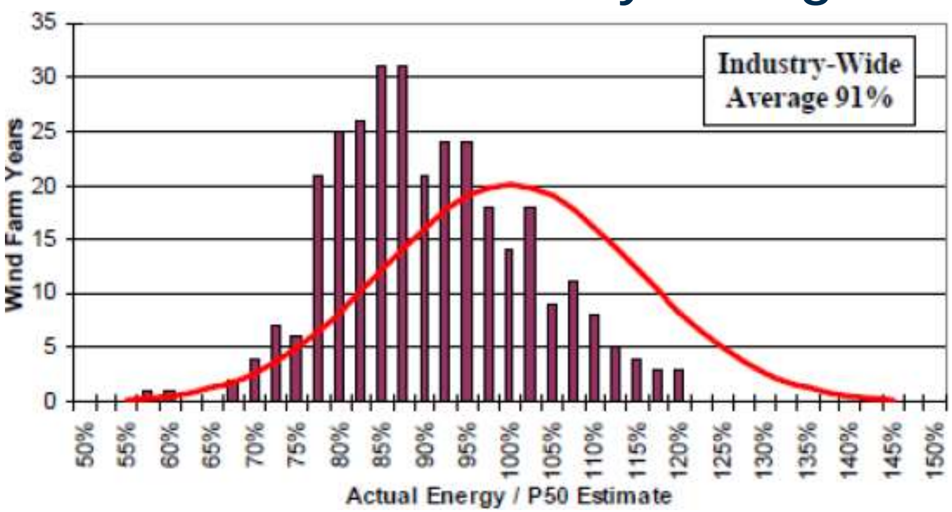
Johan N. Stander
e: jstander@csir.co.za
Gregory B. Landwehr
e: glandwehr@csir.co.za

Contents

CSIR
our future through science

Why benchmarking microscale codes?

- Wind farms not yielding the pre-construction AEP

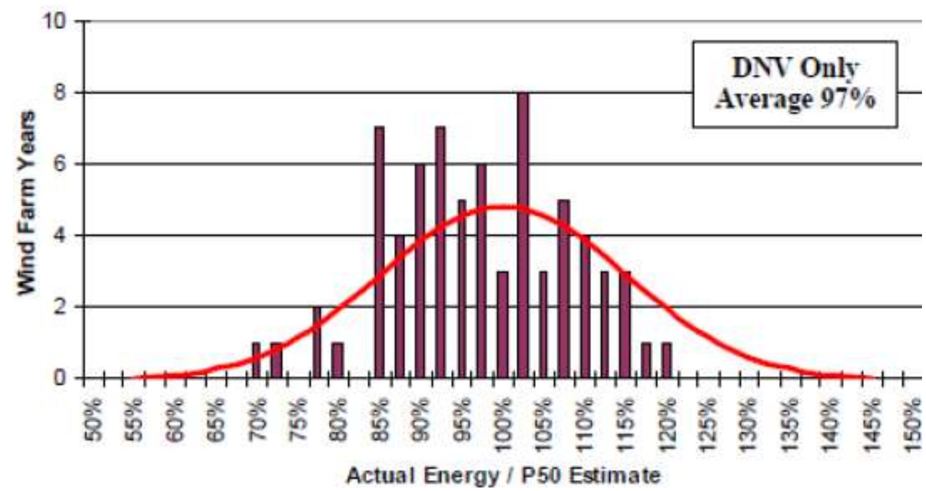


Which and what methods were applied by whom?

Normal or complex sites?

Were the assumptions conservative enough?

Old/new wind turbine mix?

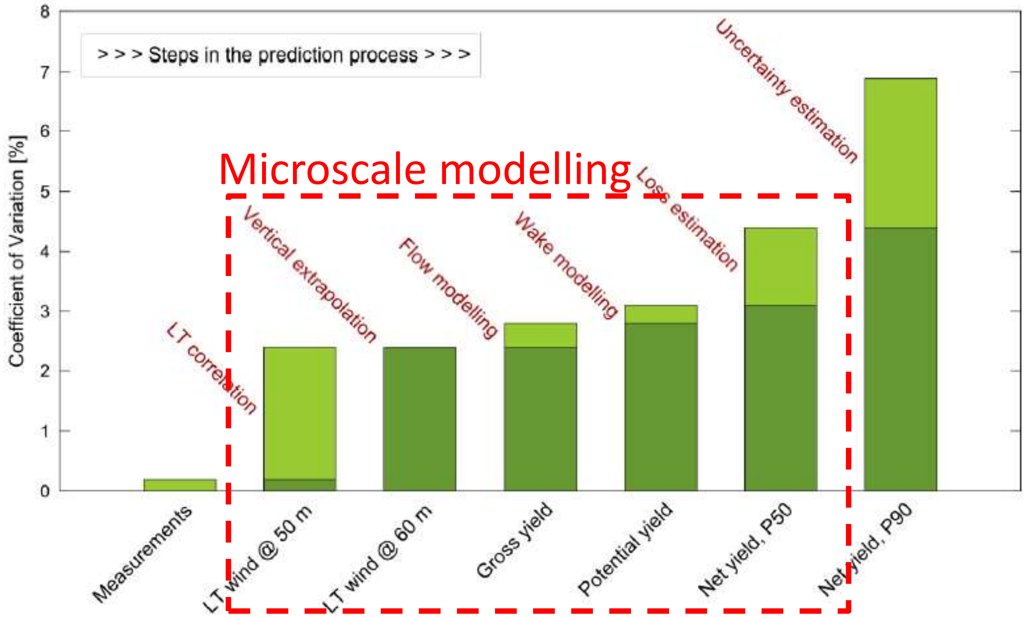


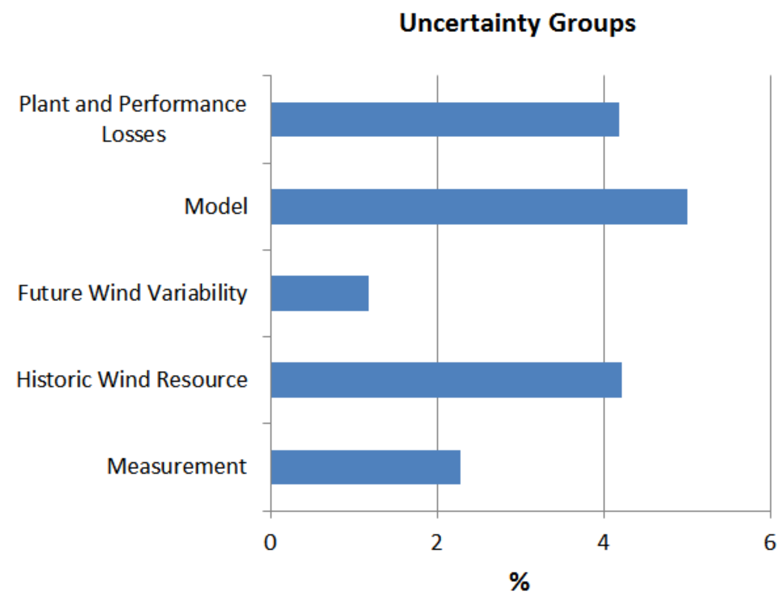
Source: DNV Doc. No.: IEWP0101, Version B, “Wind Power Project Underperformance”, 20 May 2011

our future through science

Why benchmarking microscale codes?

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





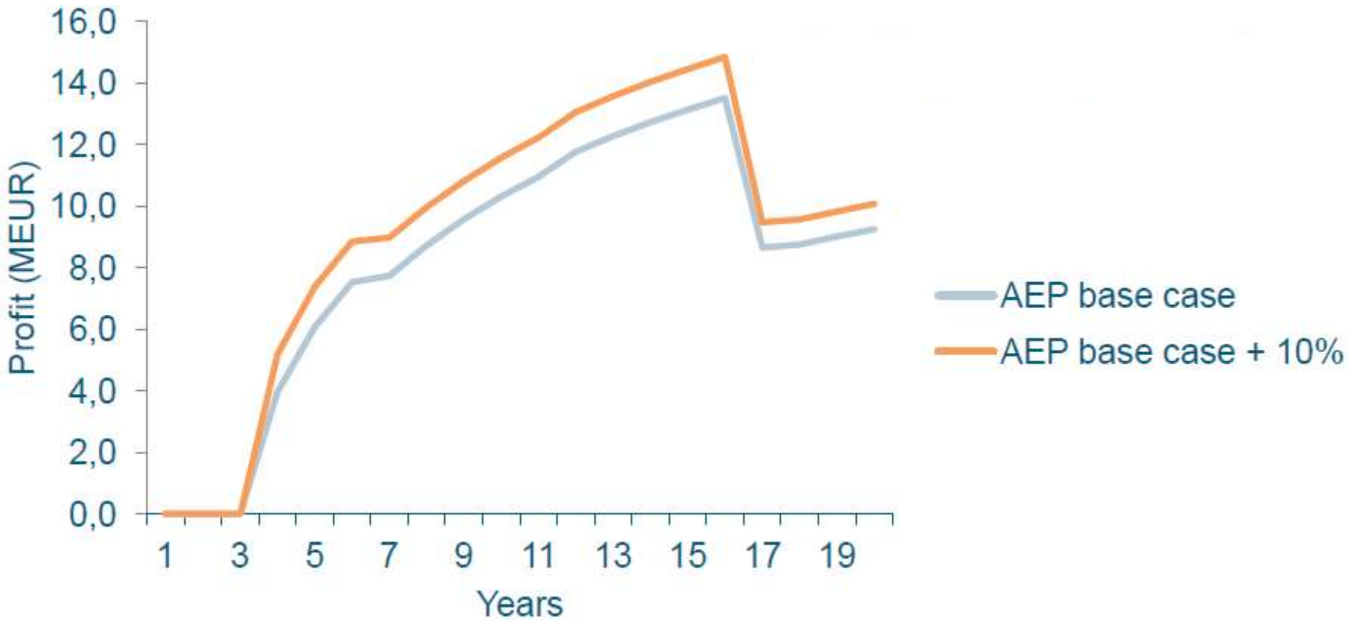
Source: Mortensen, N.G., Jørgensen, H.E. 2013. Comparative Resource and Energy Yield Assessment Procedures (CREYAP) Pt. II. URL: www.ewea.org/events/workshops/wp-content/uploads/2013/06/EWEA-RA2013-Dublin-5-5-Niels-G-Mortensen-DTU-Wind-Energy.pdf

our future through science

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: Gravdahl, 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%2FArrangementer%2FMulticonsult+WindSim+Norwea+18.03.14%2F140319_WindSim_Multiconsult_NORWEA_ARG_Wind_farm_layout_design.pdf

our future through science

Benchmarking setup

- A number of microscale modelling codes considered
  e.g. WAsP, Meteordyn, OFWind, WindPro, WindFarmer, etc.

- Codes – different favors 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

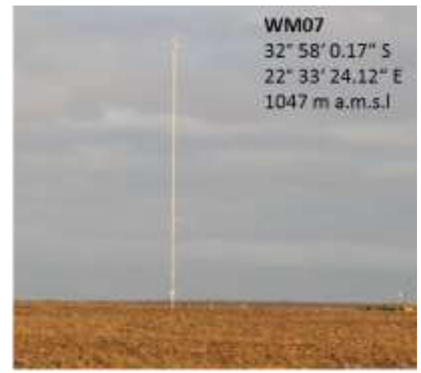
- Goal: flow modelling capability comparison and expose
  data shortfalls

our future through science

Benchmarking setup

- Comparison involves a normal and a complex sites

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



Source: WASA 2017. Wind Atlas of South Africa. URL: www.wasaproject.info

our future through science

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

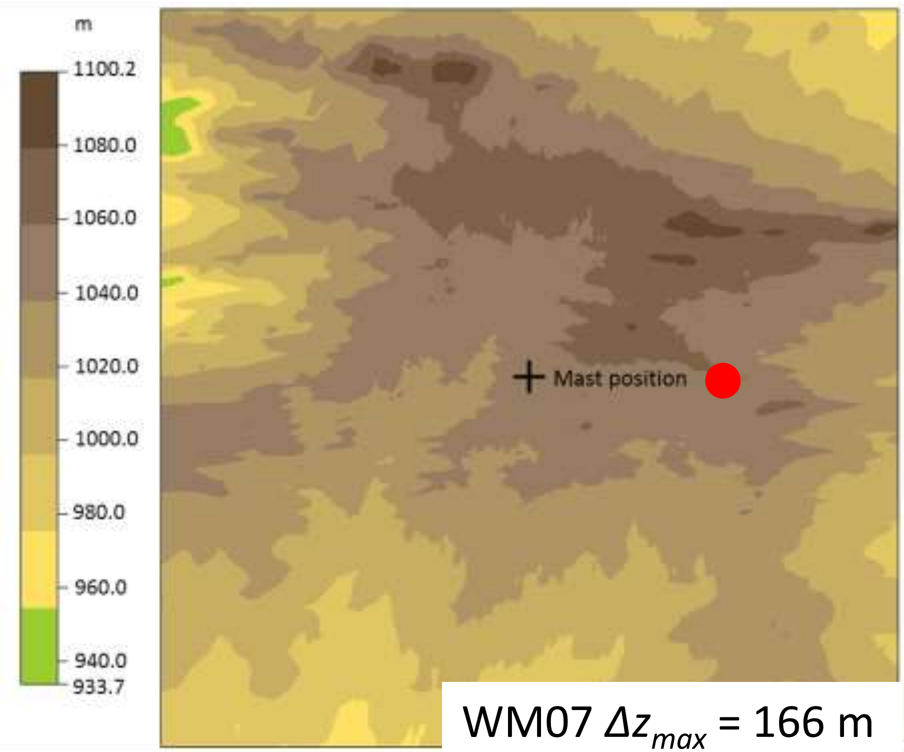
  gross AEP involving a dummy 2 MW wind turbine

CSIR
our future through science

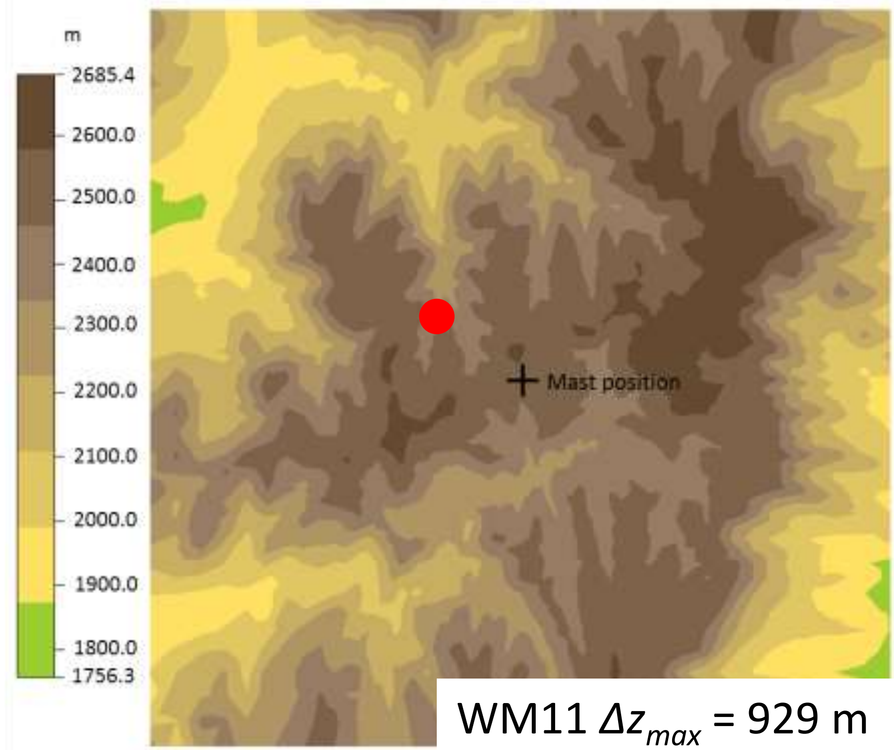
Modelling: Pre-processing

- Terrain data - topography

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



WM07 Δz_{max} = 166 m



WM11 Δz_{max} = 929 m

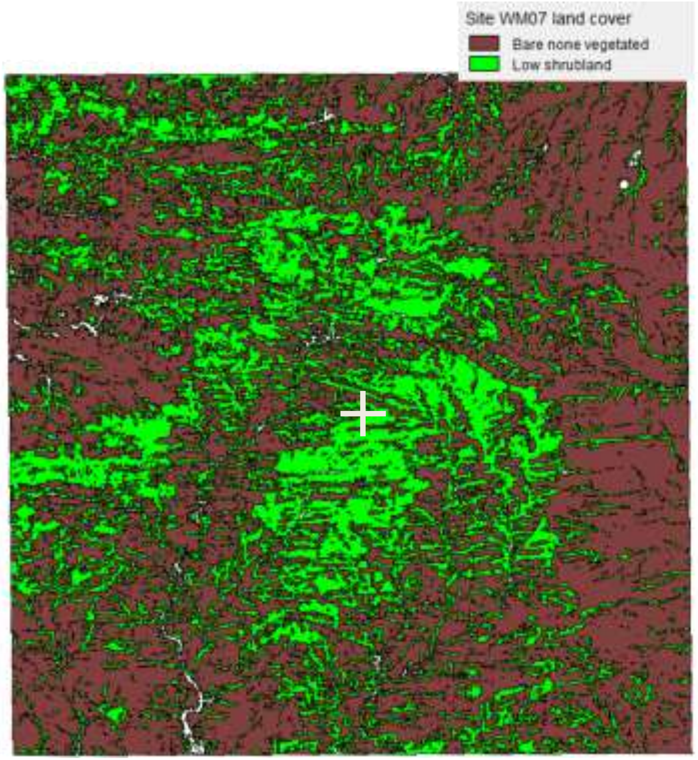
● indicates wind turbine location

CSIR
our future through science

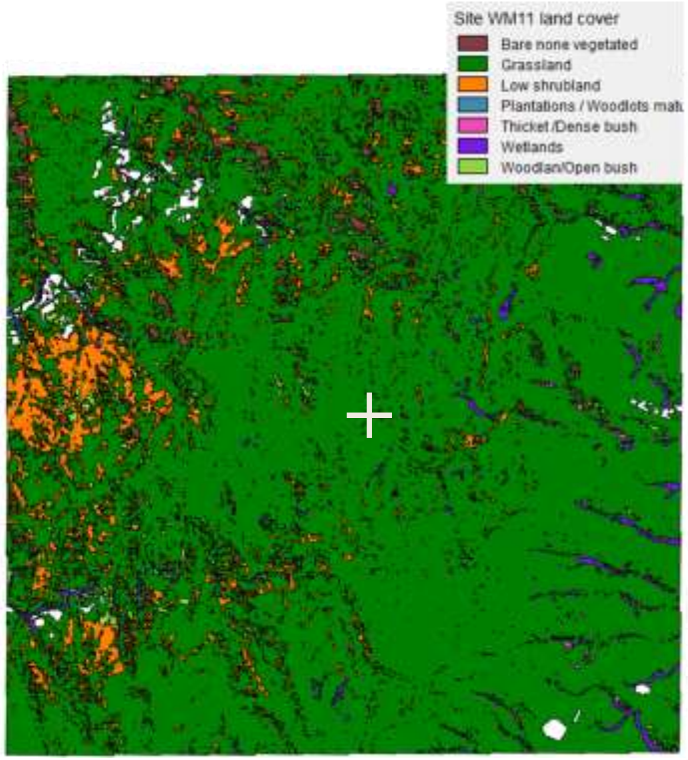
Modelling: Pre-processing

- Terrain data - orography

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



z_0 = 0.03 to 0.1 m → 0.06 m



z_0 = 0.05 to 0.1 m → 0.05 m

our future through science

Modelling: Pre-processing

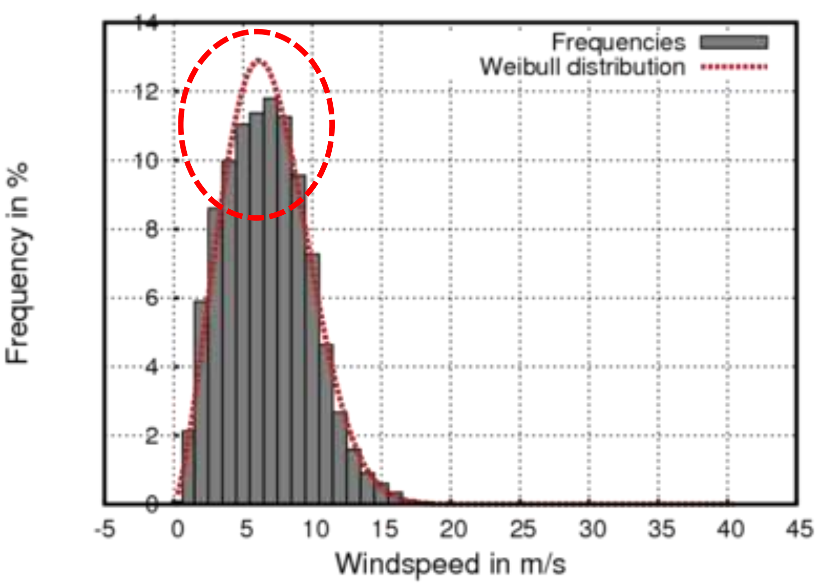
- Climatology – local wind climate – WM07

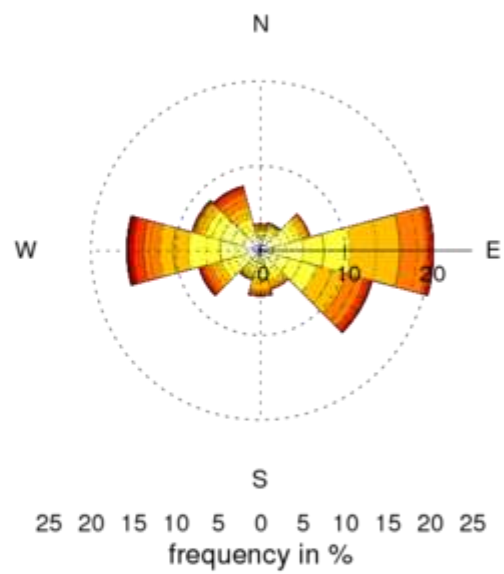
derived from 2016 10-minute average observations (*u, uº, Θ, ΔΘ, ω, p*)

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: ΔF ~ 1 %



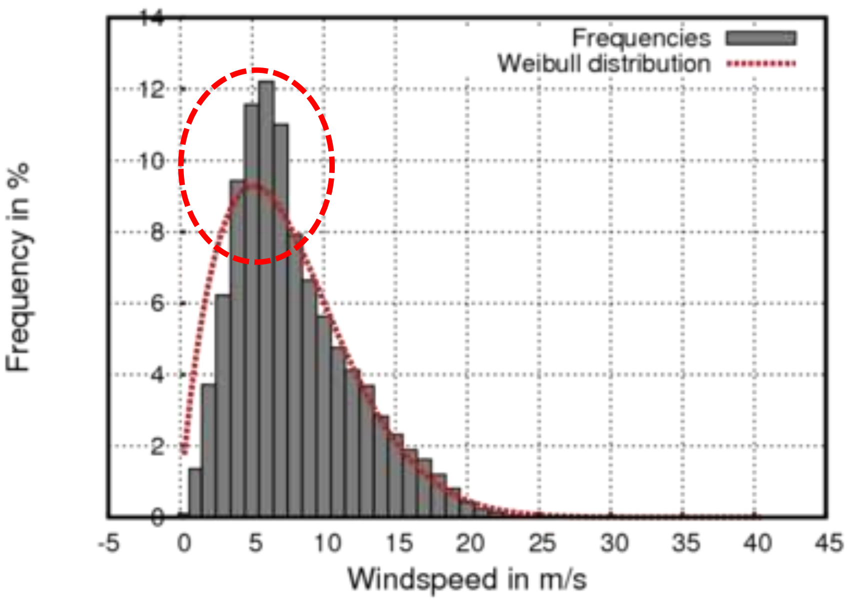


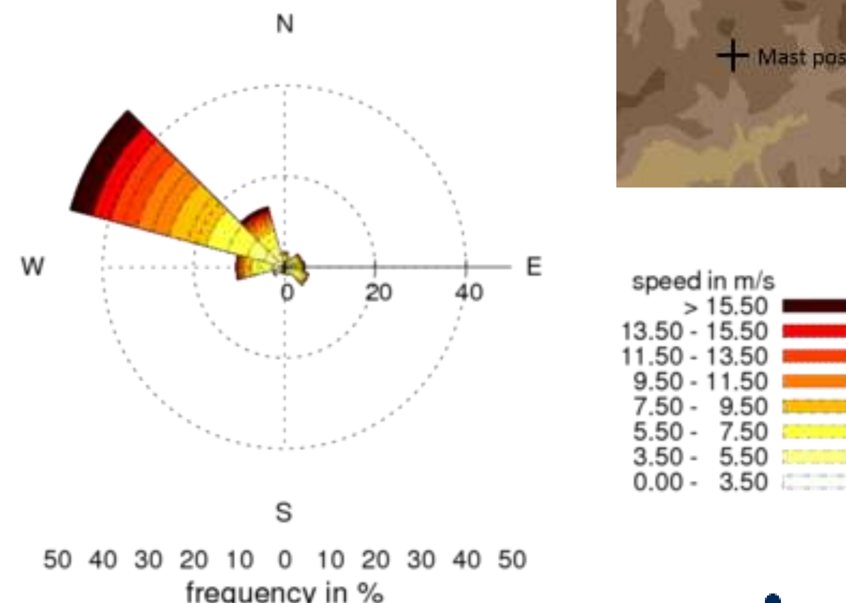
Modelling: Pre-processing

- 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: ΔF ~ 3 %





our future through science

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 ^{o}C/km]	**Conditional stability [-10 ^{o}C/km < ELR < -6 ^{o}C/km]**	**Neutral [ELR ≈ -10 ^{o}C/km or ELR ≈ -6 ^{o}C/km]**	**Stable [ELR > -6 ^{o}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

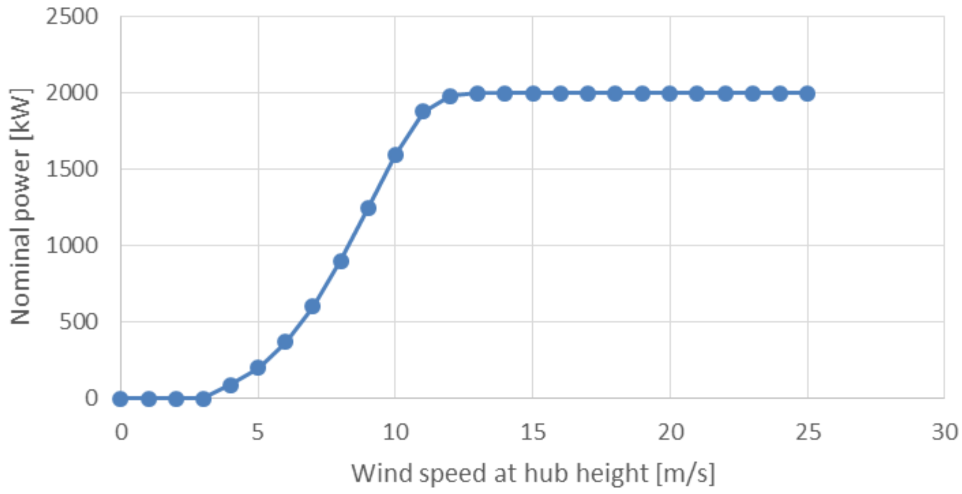
our future through science

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



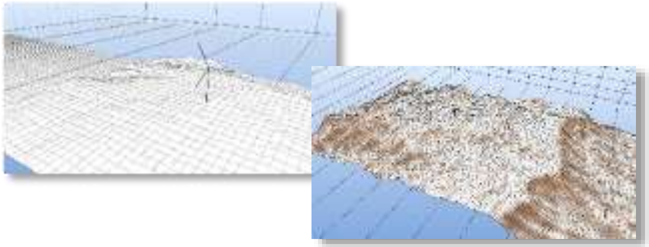
u [m/s]	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15 to 25
P [kW]	0	0	0	0	87	201	371	601	901	1243	1591	1876	1979	1999	2000	2000

CSIR our future through science

Modelling: Pre-processing

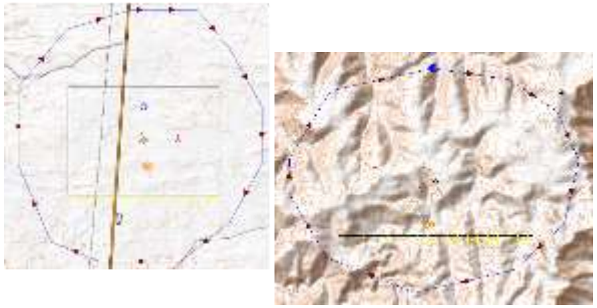
- Linearized code setup sequence

Topographical data → *Elevation Grid Data Object*



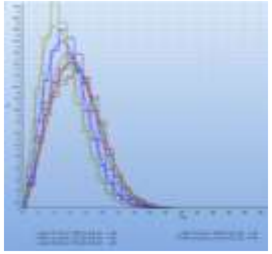
↓

Orographic data → *Line Data Object (polygons)*



↓

Climate data → *Meteo-Object*



↓

Wind turbine data → *WTG Object*

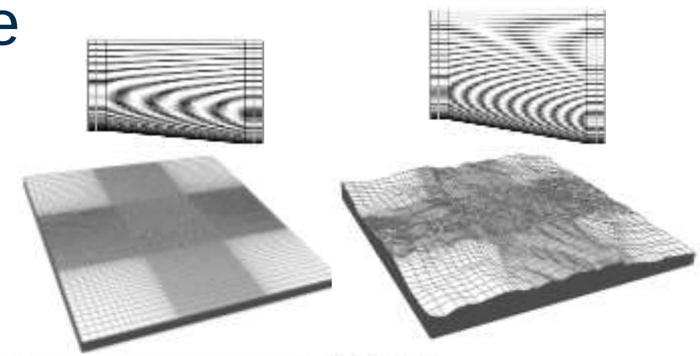
CSIR
our future through science

Modelling: Pre-processing

- Non-linearized code setup sequence

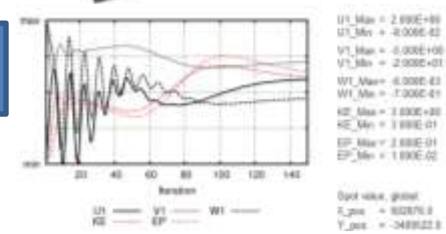
Topographical and orographic data → *Terrain module*

*meshing



Generate wind field → *Wind Field Module*

*grid independence



Climate data → *Climatology Object*

Wind turbine data → *Wind Turbine Object*

CSIR our future through science

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-ε 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)

CSIR
our future through science

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^2] @ 80 m a.g.l	*Resource*	*Results* and *Wind Resources*
Wind profiles [m/s] in prevailing wind direction	*STATGEN*	*Results* and *Energy*
Gross AEP [MWh/a] specific to 2 MW dummy	*Park*	*Results* and *Energy*

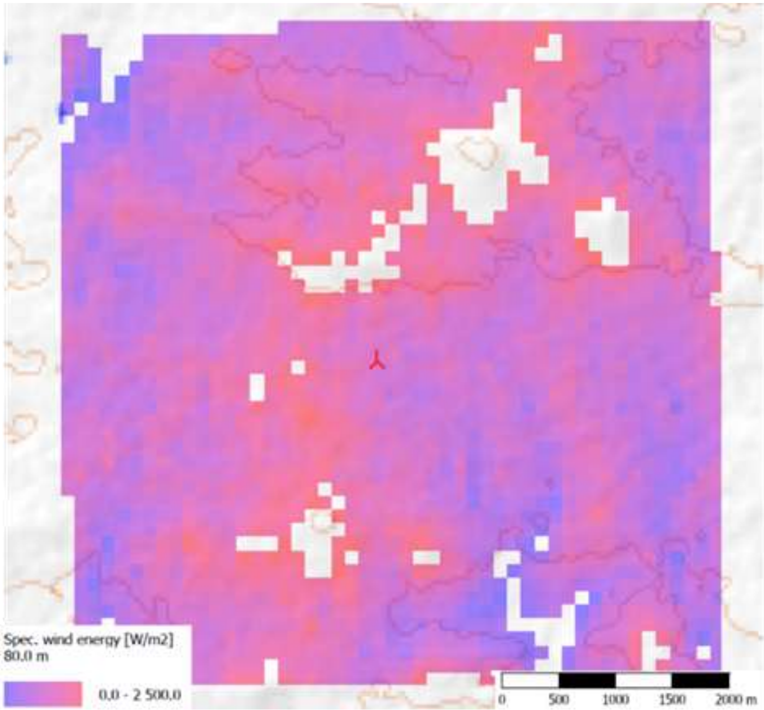
our future through science

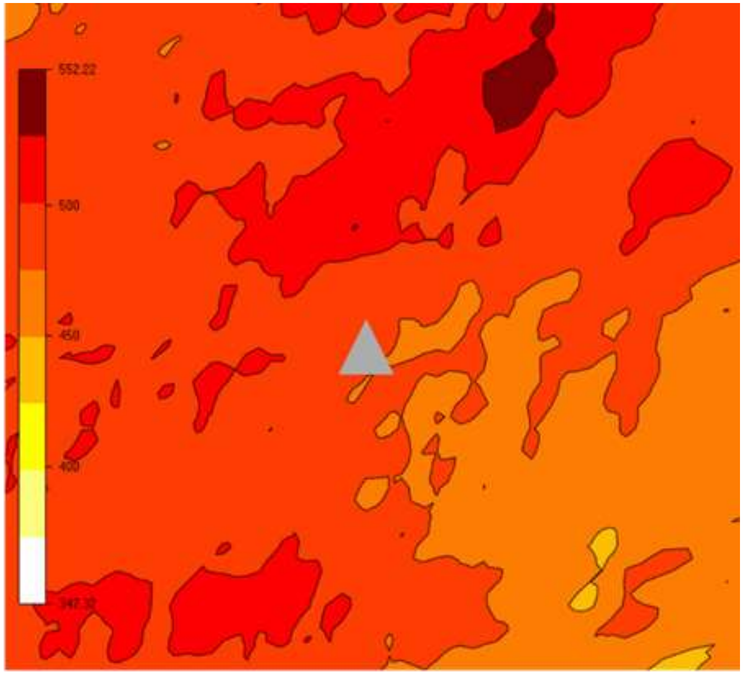
Results

- Wind resource map – W/m^2 @ 80 m a.g.l

Visual comparison – pattern and value range

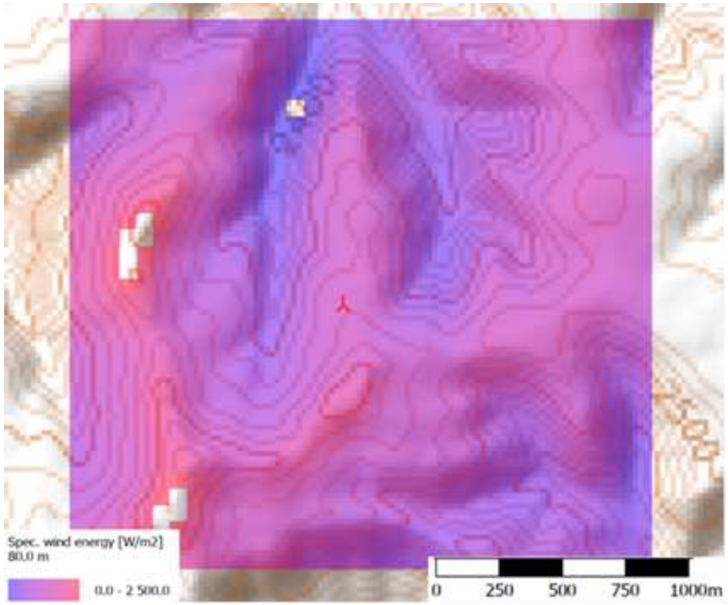
WM07

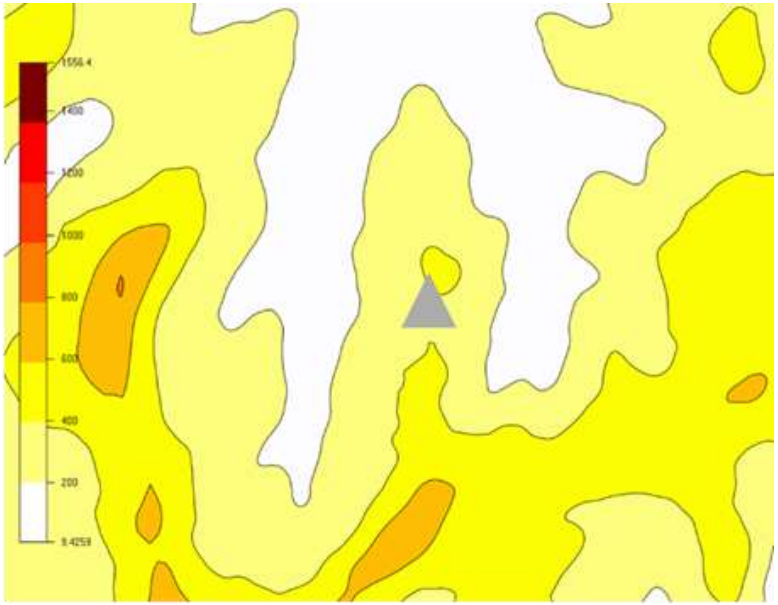




Results

WM11



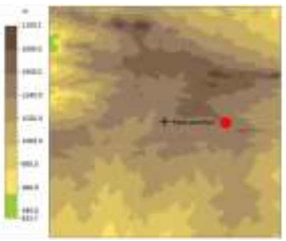


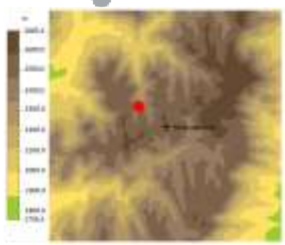
Results

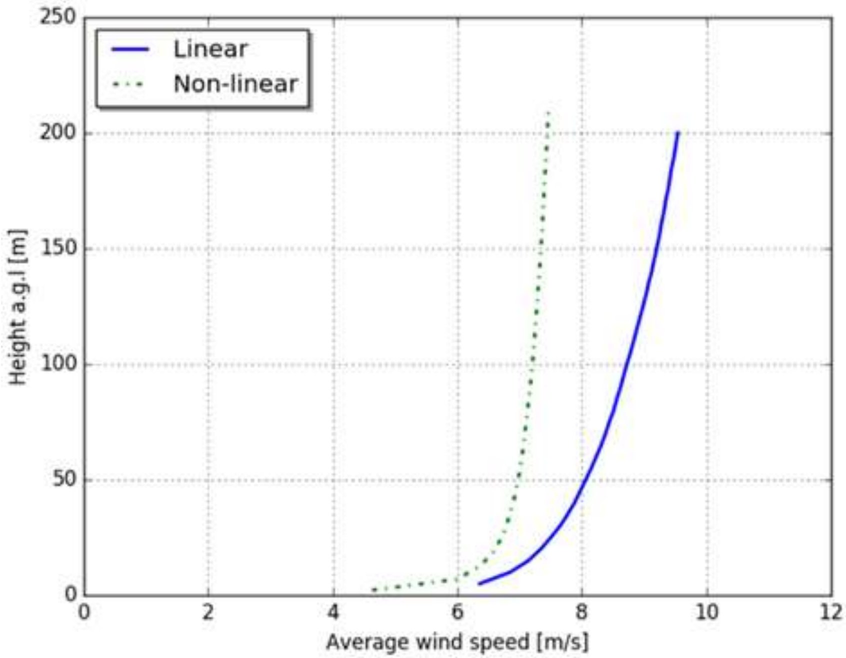
- Wind profiles – prevailing wind direction

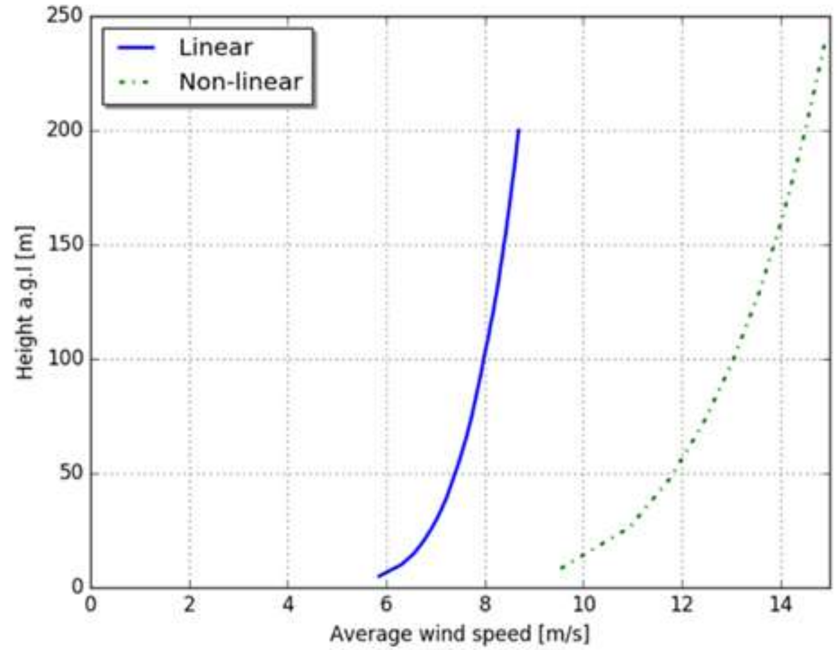
  profile shapes indicates different stability conditions

  shear velocity offset not understood









our future through science

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

CSIR
our future through science

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

CSIR
our future through science

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

CSIR
our future through science

Thank you

our future through science

Johan Stander (jstander@csir.co.za)