What is a wind atlas and where does it fit into the wind energy sector?

DTU Wind Energy

By
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Head of section : Meteorology & Remote sensing
Program manager : Siting & Integration
Outline

• Why a wind atlas?
• A little history and future
• Who needs a wind atlas and what is it used for?
• What is a state-of-the-art wind atlas?
• The WASA project
  – Measurement programme for validation
  – Observational Wind Atlases
A small reminder
- Ice core data from Antarctic & global temperature

Global Land and Ocean Temperature Anomalies, January-December

Temperature variation (ΔT)

Carbon Dioxide

Dust concentration
Why a wind atlas - 1

The wind turbine – air mass and speed is the fuel

3 MW wind turbine
Nominal revolutions: 16 rpm

Weight
Nacelle: 70 t
Rotor: 41 t
Towers: 100 m - 250 t

Rotor
Diameter: 90 m
Area swept: 6,362 m²

Football field: $68 \times 105 = 7,140 \text{ m}^2$

Mass flux at wind speed of 10 m/s:
$10 \times 6362 \times 1.225 = 77935 \text{ kg/s}$
at air density of 1.225 kg/m³
Why a wind atlas - 2

Wind provides the income in cost-benefit

- Investment costs
- Operation and maintenance costs
- Electricity production ~ Wind resources
- Turbine lifetime
- Discount rate
- Environmental benefits

Energy in wind

\[ P = \frac{1}{2} \rho U^3 \text{[W/ m}^2\text{]} \]

Wind speed \( U \text{[m/s]} \)

10% error on speed \(
\rightarrow
30\%\) error on energy

Modelling is necessary and it must be good
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History of wind atlases – some milestones

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980</td>
<td>The Wind Atlas Method was born at Risø (now DTU Wind Energy)</td>
</tr>
<tr>
<td>1981</td>
<td>First wind atlas for Denmark (observational)</td>
</tr>
<tr>
<td>1989</td>
<td>European Wind Atlas (observational)</td>
</tr>
<tr>
<td>1990+</td>
<td>DTU Wind Energy is starting to do research in using NWP tools</td>
</tr>
<tr>
<td></td>
<td>• Downscaling</td>
</tr>
<tr>
<td></td>
<td>• Generalization</td>
</tr>
<tr>
<td></td>
<td>• First KAMM then WRF</td>
</tr>
<tr>
<td>2006</td>
<td>Wind Atlas for Egypt (KAMM)</td>
</tr>
<tr>
<td>2012</td>
<td>Wind Atlas for South Africa (KAMM)</td>
</tr>
<tr>
<td>2013</td>
<td>World Bank ESMAP starts RE Resource Mapping projects</td>
</tr>
<tr>
<td>2014</td>
<td>Wind Atlas for South Africa (WRF)</td>
</tr>
<tr>
<td></td>
<td>• First WRF-based Numerical Wind Atlas – applying new generalisation</td>
</tr>
<tr>
<td></td>
<td>method for time-series mesoscale data</td>
</tr>
<tr>
<td></td>
<td>• First High-Resolution Wind Resource Map – applying new</td>
</tr>
<tr>
<td></td>
<td>automated microscale modelling running WAsP in large geographical</td>
</tr>
<tr>
<td></td>
<td>areas</td>
</tr>
<tr>
<td></td>
<td>• First Extreme Wind Atlas using DTU method</td>
</tr>
</tbody>
</table>
Numerical Wind Atlas work with mesoscale modelling

1999 British coastal areas (selected)
1999 Ireland
2000 Northern Sweden
2000 Gulf of Suez, Egypt
2000 Western coast of Turkey
2000 North coast of Morocco
2001 Northern Portugal and Galicia, Spain
2001 Denmark
2001 Faroe Islands
2002 Turkey (west of Adana)
2002 Tunisia
2002 Morocco (NW portion of the country)
2002 Egypt (most of country covered)
2003 Corsica - mesoscale flow study
2003 Tanzania - mesoscale flow study
2003 Portugal - mesoscale flow study
2004 Bangladesh *
2004 Ethiopia *
2004 Kenya *
2004 Nepal *
2006 Egypt
2007 Cape Verde
2007 India Wind Atlas
2008 Cambodia
2008 United Arab Emirates
2008 North Eastern China
2010 South Baltic Wind Atlas
2012 Mali *
2012 NORSEWind, North and Baltic Seas *
2012 Lesotho Wind Energy *
* indicates projects for which results are freely and publicly accessible

DTU Wind Energy, Technical University of Denmark
Projects initiated 2013-2015:

- Vietnam
- Zambia
- Pakistan
- PNG
- Maldives
- Tanzania
- Ethiopia
- Nepal
- Lesotho

Wind Atlas for Vietnam

preliminary Phase 1

Mean generalized wind speed
Continued EU research project 2015-2020
New European Wind Atlas (NEWA)

Long-Term goal to reduce the uncertainty to 3 % on modelling of wind everywhere in 2030 (a very ambitious goal)

Sub-goals 2020 for this project

i. Open source model chain from Global models to micro scale models (to be used to characterize diurnal cycles)

ii. Create experiments to verify the models (Forest, Complex terrain, Forested complex terrain, Coastal zones, High altitude)

iii. Provide a database of standardized input to models (define resolutions on roughness & terrain – Wind geo-server)

Methods

• Develop the interface between microscale and mesoscale models
• Develop microscale models that include stability (for the characterization of the diurnal variations)
• Perform high quality measurement campaigns
• Verify the developed models against measurements
• Develop a standard for validation of models

Budget – 13 mio Euro

Partners – 7 EU member countries (Denmark lead)
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The wind energy sector

Government policy makers

Local planning authorities

Turbine manufacturers

Research and development institutions

Wind energy consultants

Schools and universities

Power system operators

Power market regulators

Wind farm developers

Financial institutions
Who needs a wind atlas – the WB

Governments
- Quantifies resource potential
- Helps identify best areas for development
- Improved data for setting policy incentives

Commercial Developers
- Information on high potential areas
- Reduces project uncertainty and risks
- Source of validation data for site assessment

Expert Community
- Contributes to IRENA Global Atlas
- Supports basic and applied research
- Methodological and modeling improvements

Source: World Bank - ESMAP
## Users and uses

<table>
<thead>
<tr>
<th>Group</th>
<th>Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Authorities</td>
<td>Policies, regulations and plans</td>
</tr>
<tr>
<td>Planners</td>
<td>Resource and development planning</td>
</tr>
<tr>
<td>Investors, owners and banks</td>
<td>Financial planning, risk assessment and decisions</td>
</tr>
<tr>
<td>Developers (small and large)</td>
<td>Project development</td>
</tr>
<tr>
<td>Industry (small and large)</td>
<td>Project design and implementation, Wind turbine design and development</td>
</tr>
<tr>
<td>Power sector</td>
<td>Power system planning, development and operation</td>
</tr>
<tr>
<td>Consultants</td>
<td>Independent expertise and tools development</td>
</tr>
<tr>
<td>Academic community</td>
<td>Research, tools development &amp; education</td>
</tr>
</tbody>
</table>
Wind Atlas used for planning of renewable energy development in South Africa

SEA Progress and Study Areas

DEA National Wind and Solar PV SEAs
To facilitate the efficient and effective rollout of wind and solar PV energy in SA

Webpage: www.csir.co.za/nationalwindsolarsea

SEA Data available for download & public comments

http://www.csir.co.za/nationalwindsolarsea/

DTU Wind Energy, Technical University of Denmark
Application for project development
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• **What is a state-of-the-art wind atlas?**
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What is a wind atlas?

A wind atlas is a generalized set of wind climate information
• at a given location
• or at many grid points – representing a region

Much more than a simple map containing mean wind speed
• **Verification** with observations
• **speed** and **direction statistics**
• A **data base** which allows much more detailed calculations
Wind Atlas for South Africa 2014
a graphical representation

High-Resolution Wind Resource Map using WRF-based NWA, March 2014
mean wind speed (m/s) at 100 m agl in a grid spacing of 250 m.

Generalised wind speeds – WRF-based NWA, March 2014
mean wind speed [m/s] 100 m agl, fat terrain, 3 cm roughness
From mesoscale model to site conditions

- Direct approach:
  - Mesoscale model output
  - Site conditions
  - Micro corrections only

- Comprehensive approach:
  - Mesoscale model output
  - Mesoscale generalisation
  - Micro corrections
  - Microscale modelling
  - Site conditions

Numerical Wind Atlas
The verified numerical wind atlas

- A state-of-the-art wind atlas is verified by measurements
- The Wind Atlas project is designed from the beginning to include high quality measurements against which the numerical wind atlas could be checked
- This produces a “Verified Numerical Wind Atlas”

So, alongside the mesoscale modelling, the project has a second, parallel, activity:

- Numerical wind atlas
- High quality measurements
- Mesoscale modelling
- Microscale modelling
- Generalised climatological wind climates @ grid points
- Generalised wind climates @ mast locations
- Verification
Numerical Wind Atlas methodology
Downscaling from global reanalysis data + verification

Global wind data → Regional wind climate → Local surface wind

200 km × 200 km → 3 km × 3 km → 1–10 m

Verification

Mesoscale modelling

Microscale modelling

Measurements

Local surface wind
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**The WASA project**
- Measurement programme for validation
- Observational Wind Atlases
WASA information and databases

WASA products

- Reports and presentations
  [www.wasaproject.info](http://www.wasaproject.info)
- Data, methods, tools, guidelines
  [www.wasa.csir.co.za](http://www.wasa.csir.co.za)

In the WASA modelling domain wind climate data is available in grids of 3 and 5 km spacing – virtual masts.
Verification - 10 WASA masts

High quality wind measurements for verification of modelling

<table>
<thead>
<tr>
<th>WASA</th>
<th>$U_{\text{mean}} @ 61.9 \text{ m}$ - 1 YEAR</th>
<th>$U_{\text{mean}} @ 61.9 \text{ m}$ - 3 YEARS*</th>
<th>$\Delta U$</th>
<th>Data recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[m/s]</td>
<td>[m/s]</td>
<td>[%]</td>
<td>[%]</td>
</tr>
<tr>
<td>WM01</td>
<td>5.86</td>
<td>6.06</td>
<td>2.7</td>
<td>100</td>
</tr>
<tr>
<td>WM02</td>
<td>6.21</td>
<td>6.14</td>
<td>-1.8</td>
<td>93.4</td>
</tr>
<tr>
<td>WM03</td>
<td>7.09</td>
<td>7.14</td>
<td>0.0</td>
<td>100</td>
</tr>
<tr>
<td>WM04</td>
<td>6.59</td>
<td>6.71</td>
<td>0.9</td>
<td>100</td>
</tr>
<tr>
<td>WM05</td>
<td>8.64</td>
<td>8.56</td>
<td>-0.8</td>
<td>98.6</td>
</tr>
<tr>
<td>WM06</td>
<td>7.02</td>
<td>7.36</td>
<td>1.6</td>
<td>99.9</td>
</tr>
<tr>
<td>WM07</td>
<td>6.85</td>
<td>6.93</td>
<td>0.3</td>
<td>97.0</td>
</tr>
<tr>
<td>WM08</td>
<td>7.36</td>
<td>7.34</td>
<td>0.3</td>
<td>100</td>
</tr>
<tr>
<td>WM09*</td>
<td>7.58</td>
<td>8.22</td>
<td>3.0</td>
<td>99.7</td>
</tr>
<tr>
<td>WM10*</td>
<td>6.55</td>
<td>6.55</td>
<td>0.0</td>
<td>98.8</td>
</tr>
</tbody>
</table>

* 2-year periods for WM09 and WM10:
  WM09: 2010-10 to 2013-09 minus the year 2011.
  WM10: 2011-03 to 2012-02 plus 2012-10 to 2013-09.
Microscale modelling at the 10 WASA masts
Some background

- Wind-climatological inputs
  - Three-years-worth of wind data
  - Five levels of anemometry

- Topographical inputs
  - Elevation maps (SRTM 3 data)
  - Simple land cover maps (SWBD + Google Earth); water + land

- Preliminary results
  - Microscale modelling verification
    - Site and station inspection
    - Simple land cover classification
    - Adapted heat flux values
  - Wind atlas data sets from 10 sites

This data was used to verify the numerical wind atlas, but **not** to create them

Analysis show prevalence of non-neutral conditions at the sites.
Verification of the wind atlas by measurements

- So we can compare the numerical wind atlas GWC that is closest to each mast with the GWC derived from the mast data.

Please note:
- Both sets of GWCs must have the same attributes i.e.
  - Same height a.g.l.
  - Flat terrain
  - Uniform roughness

(The NWA data was also adjusted so that it was representative over the same period the met mast measurements were taken.)
Example: WASA site 1, far northwest

Observed wind atlas

Numerical wind atlas

WRF

Weighted (solid)

Re-fit (dashed)
Observational Wind Atlas

Wind speed at 80 m above ground level

WAsP resource grids from Observational Wind Atlas
- 10 x 10 km² grid
- 100 meter grid spacing
Wind Atlas for South Africa – verification of numerical wind atlas

Modelling versus measurements @ 62 m

Wind speed
- Slope: 102%
- Spread: 5.9%

Energy yield
- Slope: 105%
- Spread: 12%
Extreme Wind Atlas for South Africa
a map and much more – design winds

Model Chain

Extreme Wind Atlas

Calculation of design parameters at site
The WASA project drivers and partners

The project is an initiative of the South African Government – Department of Energy – and co-funded by:

• UNDP-GEF through the South African Wind Energy Programme (SAWEP)
• Royal Danish Embassy

Project Steering Committee:

• DoE (chair), DEA, DST, UNDP, Danish Embassy, SANEDI

Executed by:

• The South African National Energy Development Institute (SANEDI)

Implemented by:

• CSIR, UCT, SAWS, and DTU Wind Energy (formerly Risø DTU)