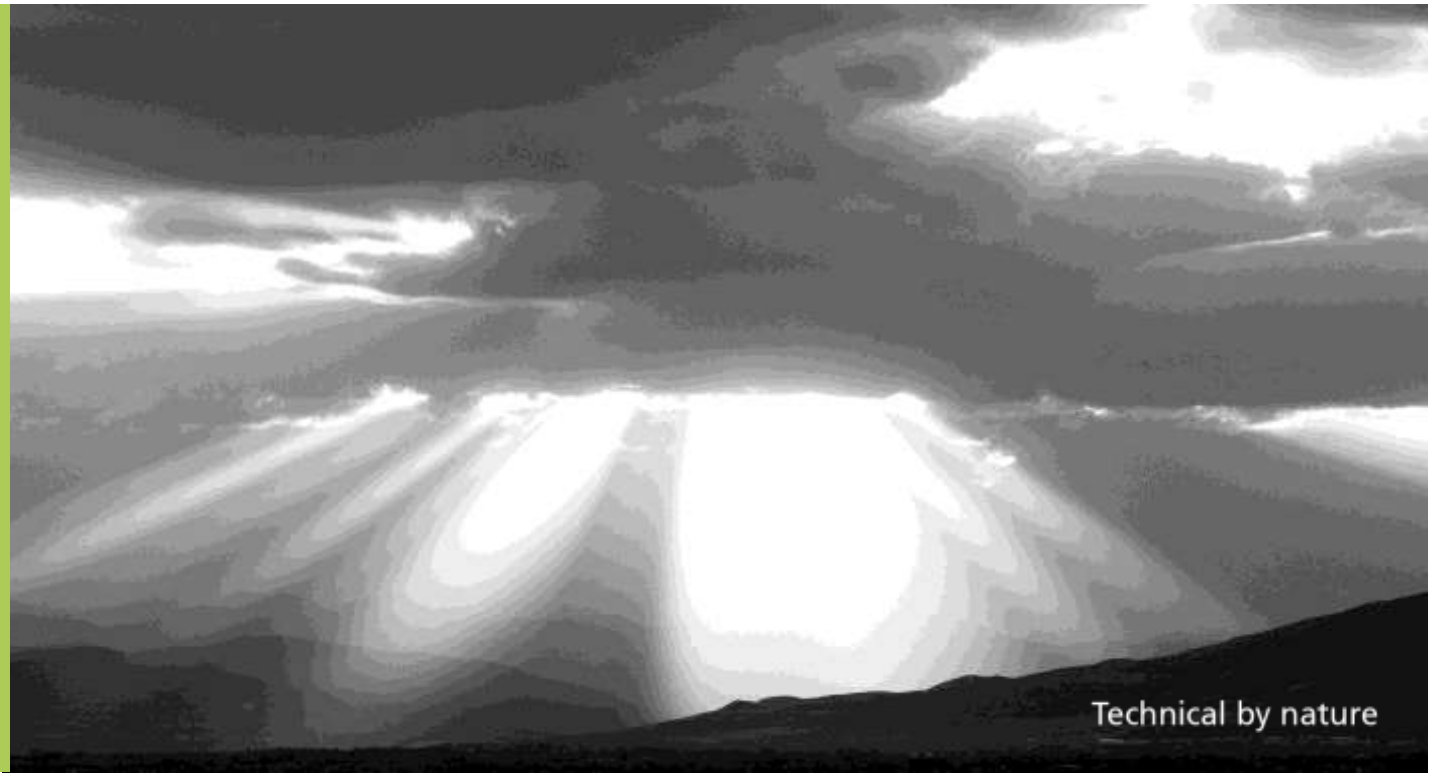
Renewable energy consultants

GL Garrad Hassan

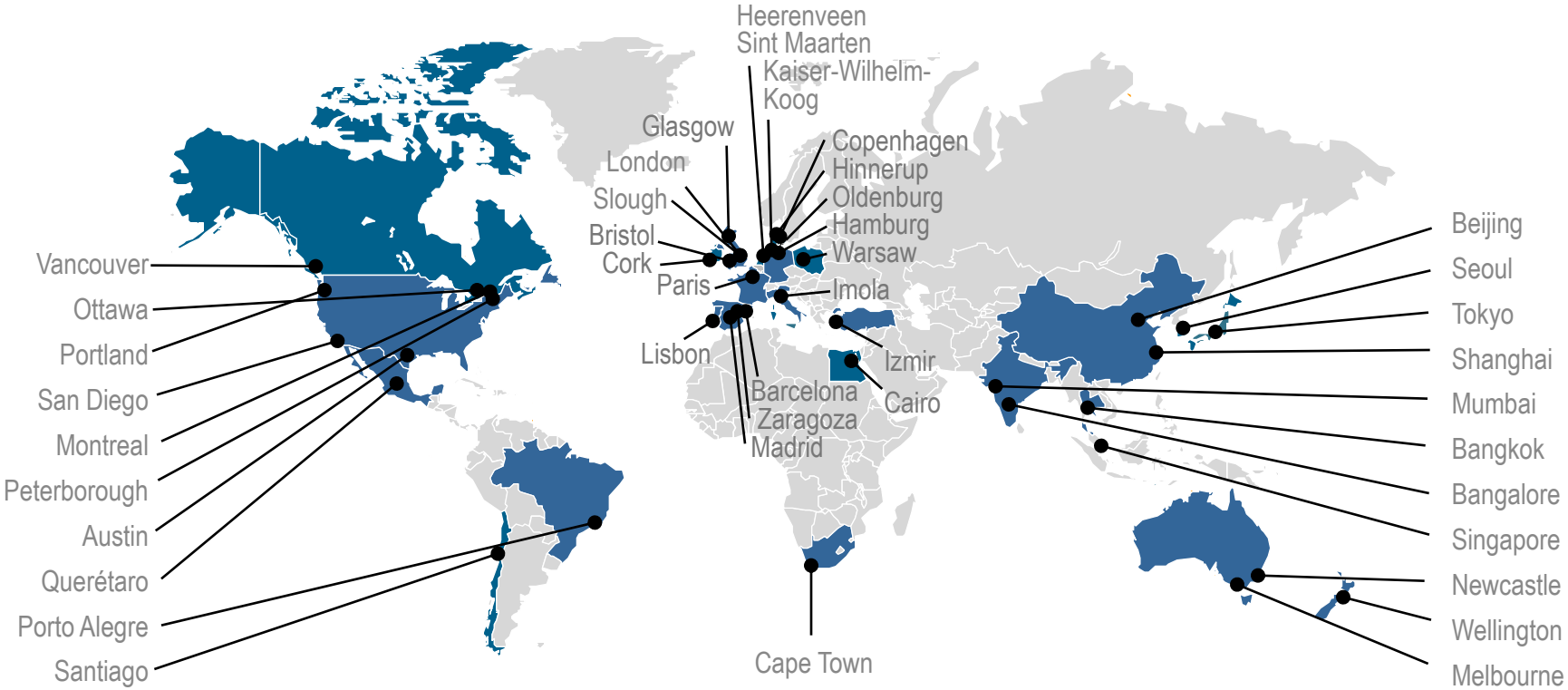
An investigation into turbine performance and wind flow modelling under cold weather driven stable atmospheric conditions

Winterwind 2013 (Östersund, Sweden - 13 February 2013)



GL Garrad Hassan – Independent Renewable Experts

Almost 1000 staff, in 44 locations, across 26 countries



Content

Cold climate driven stable atmospheric conditions in the Nordic Region:

1 - Consequences to the wind flow (challenges) and how it translates

2 - How complex CFD flow modelling can help with the wind flow modelling challenges

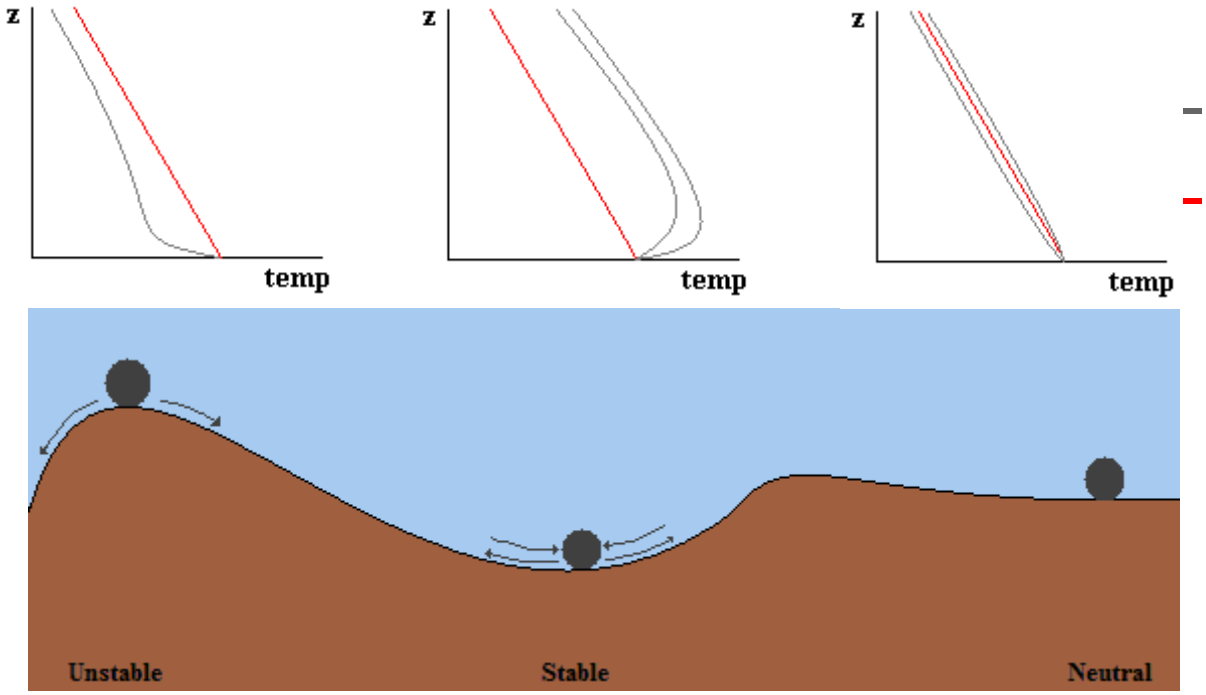
3 - Impact of high frequency of stable atmospheric conditions on turbine performance

1 – 2 – 3

Stable atmospheric conditions
What is it and how it translates

Radiative cooling driven stable atmospheric conditions

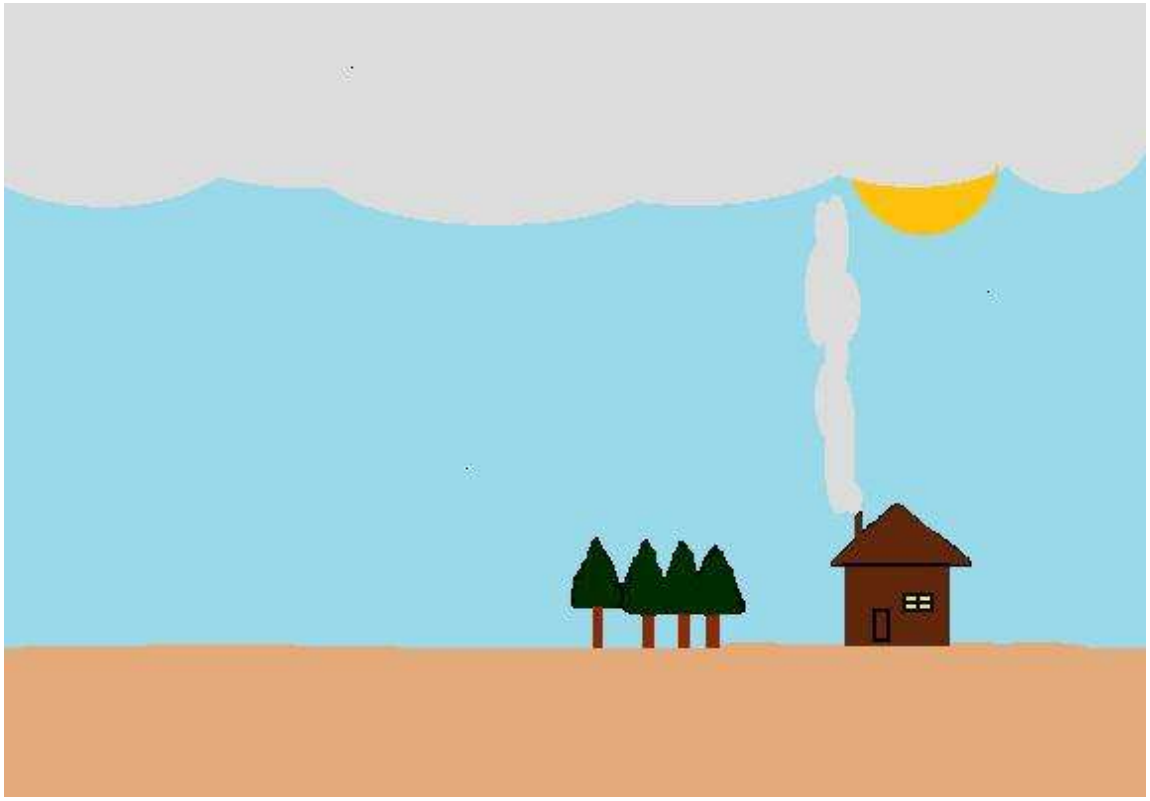
- Unstable, neutral, stable and very stable atmospheric conditions



- High frequency of stable atmospheric conditions

Radiative cooling driven stable atmospheric conditions

- When do stable and very stable atmospheric conditions happen in the Nordic region



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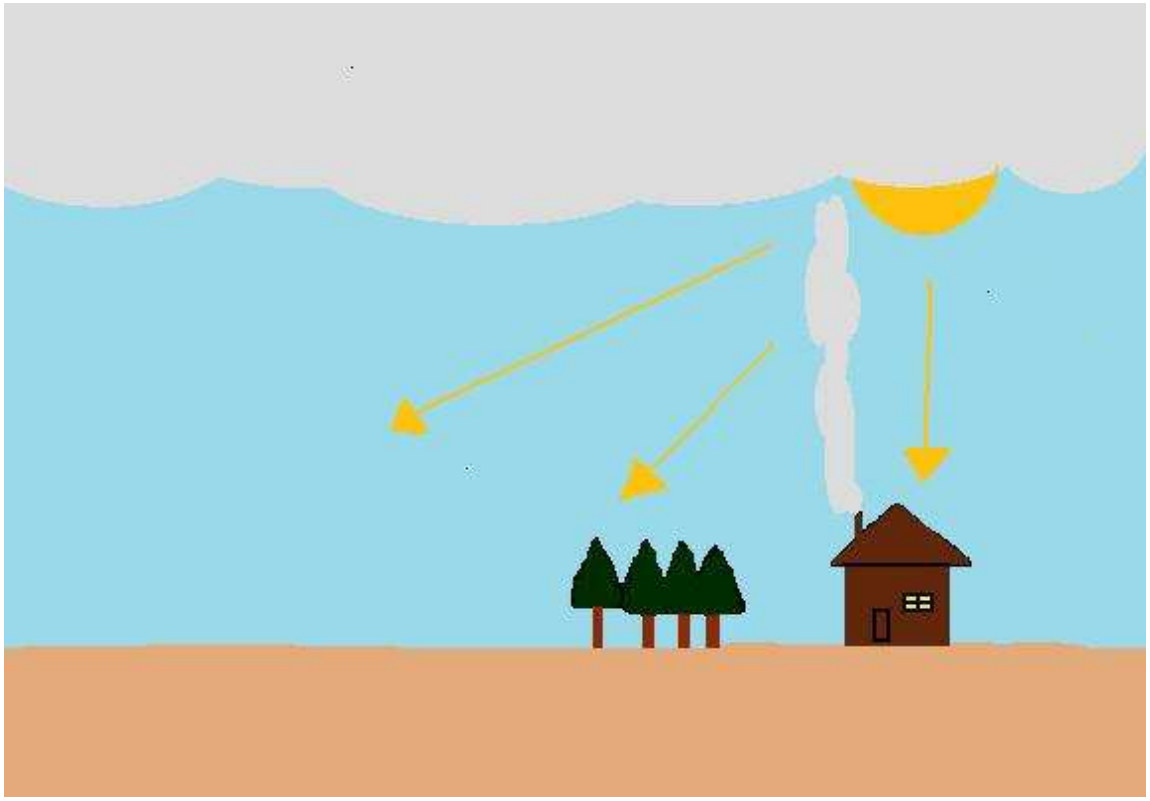

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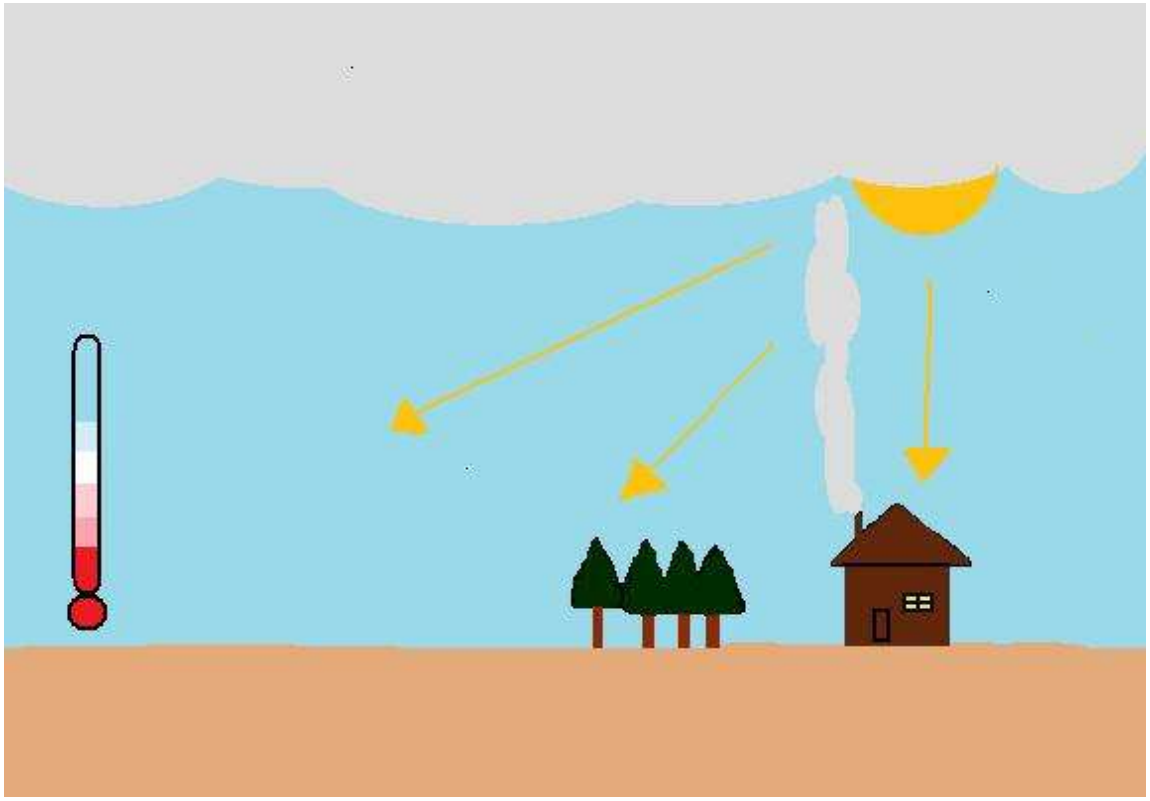

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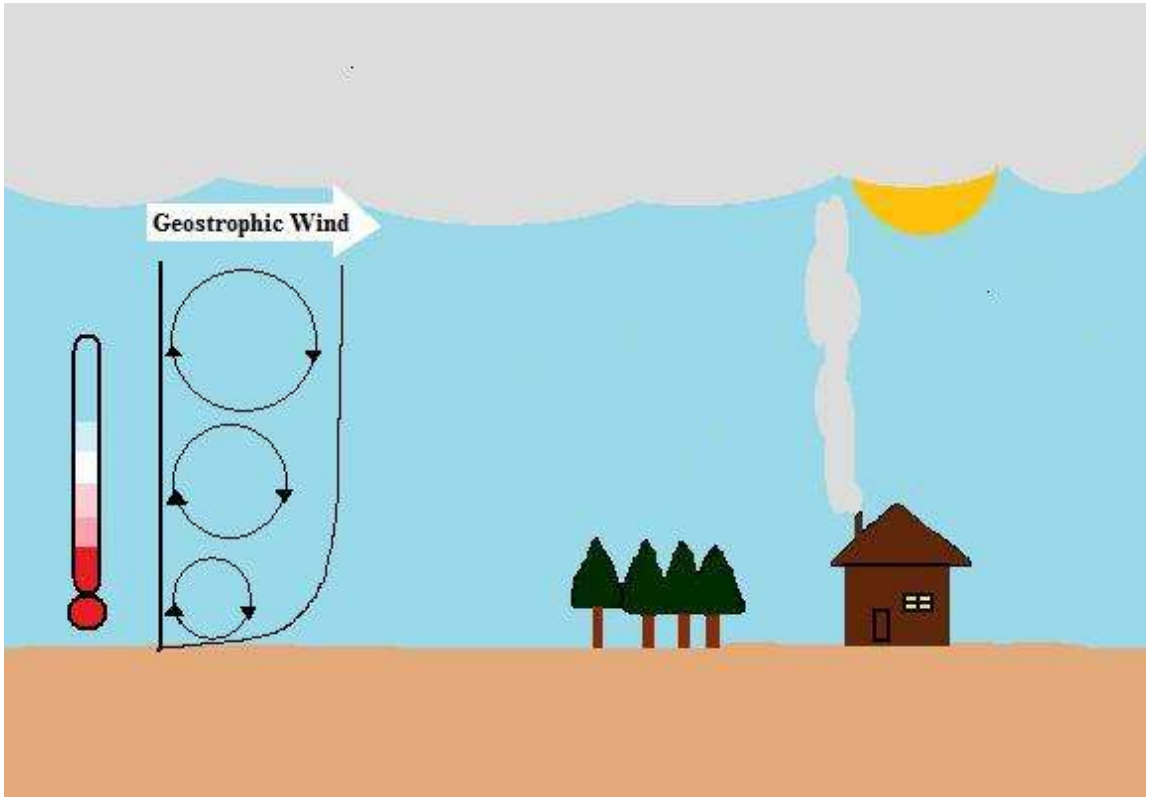

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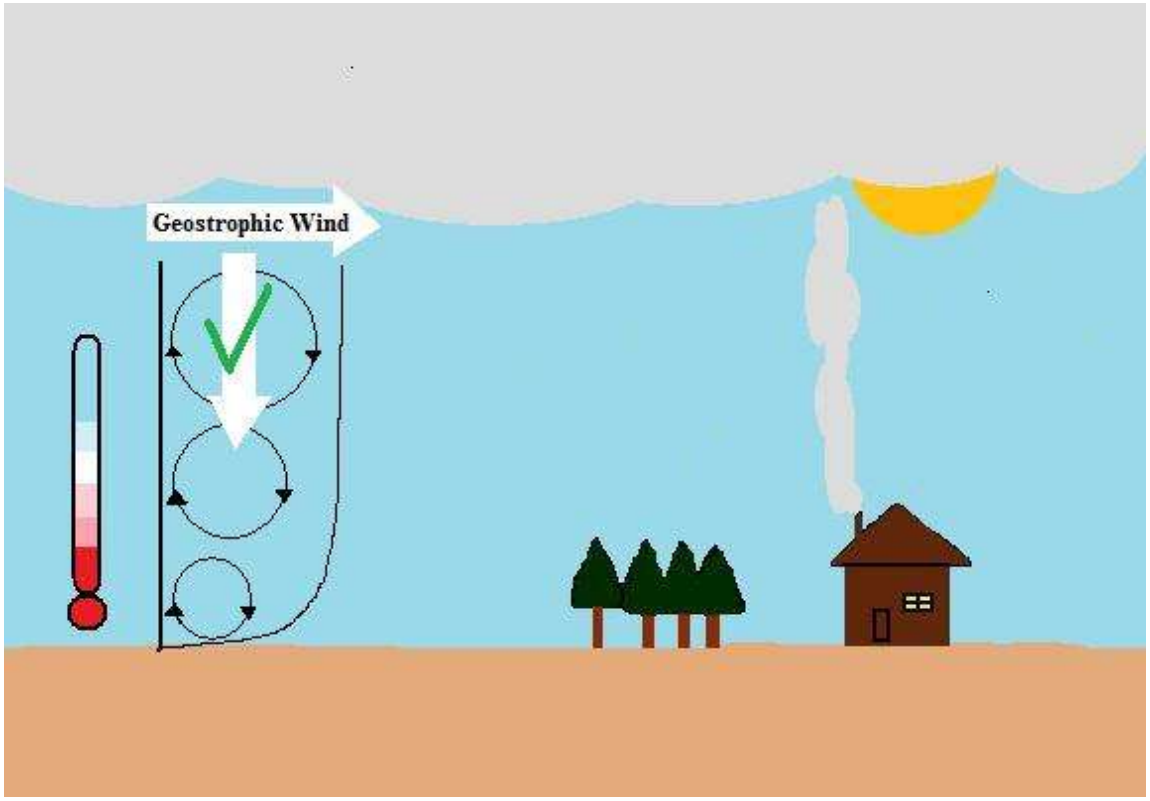

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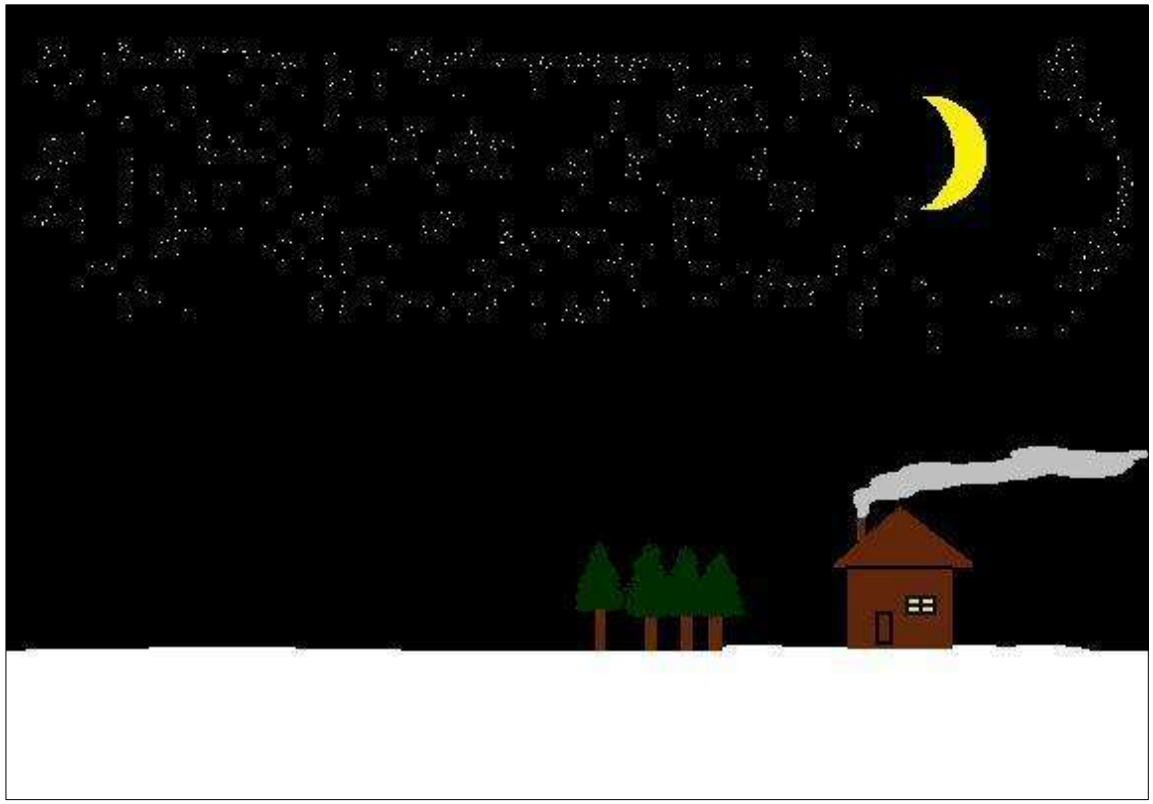

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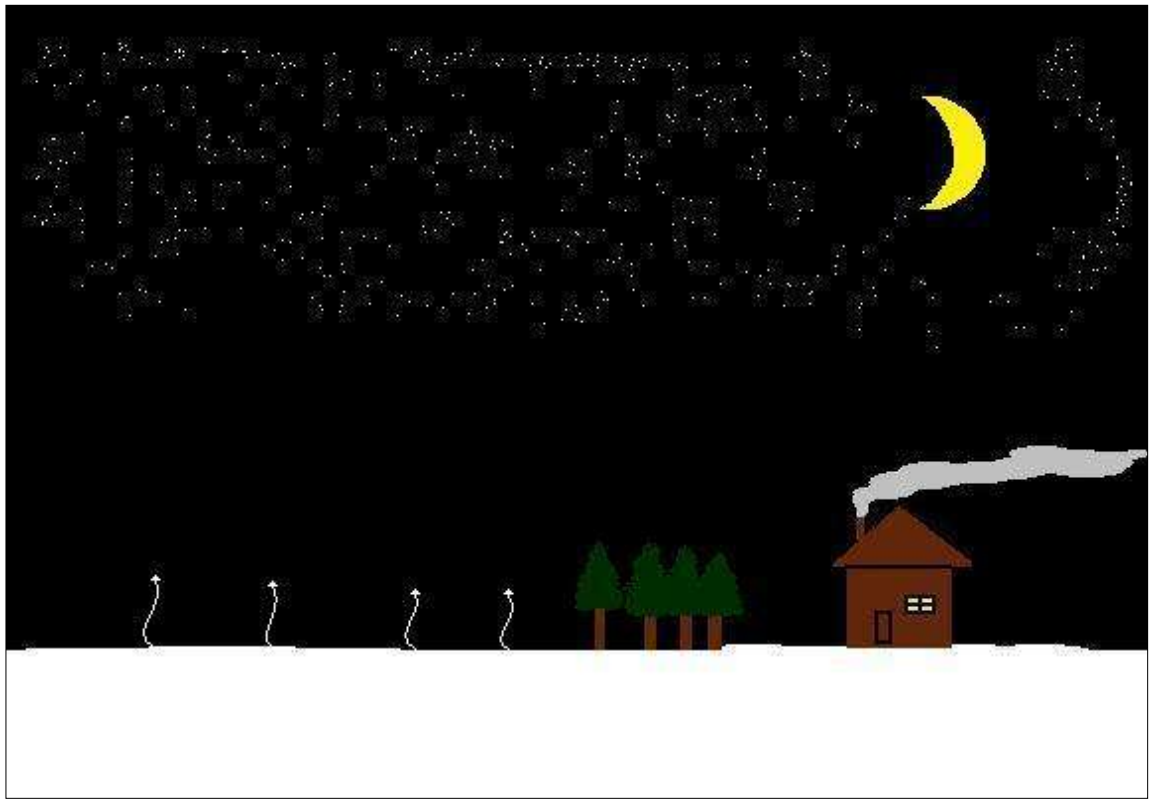

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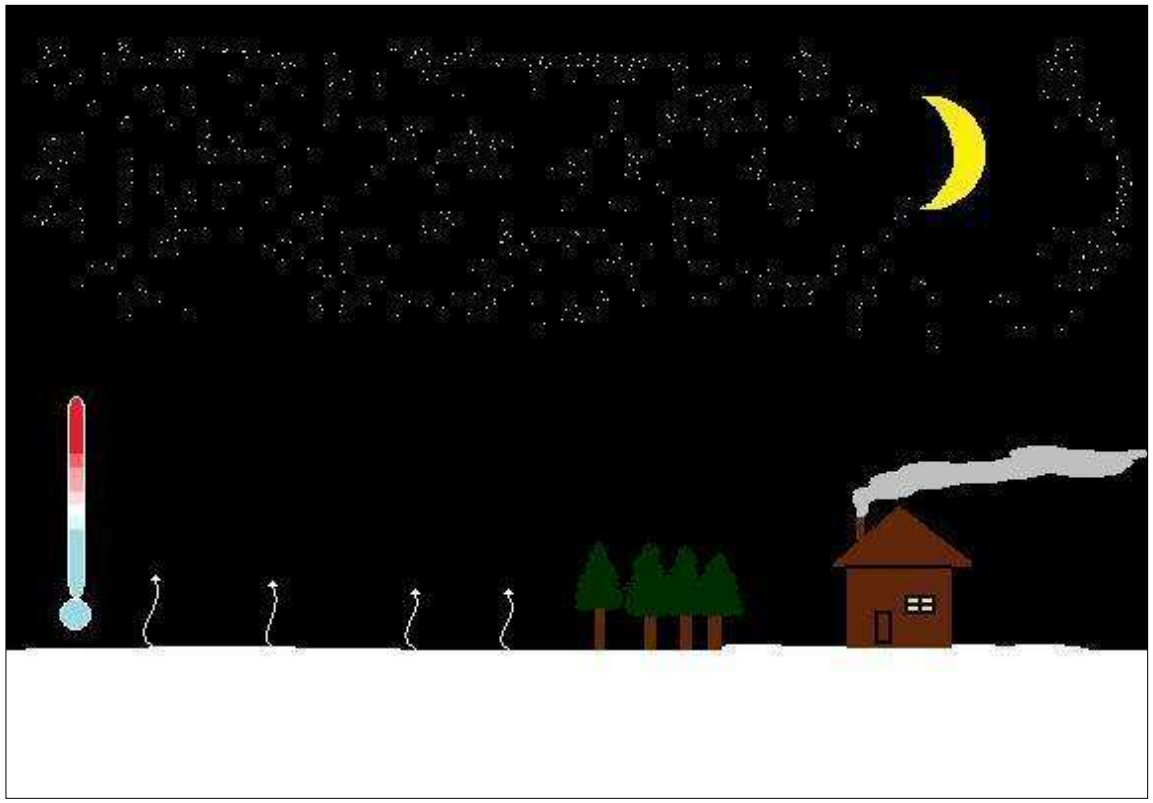

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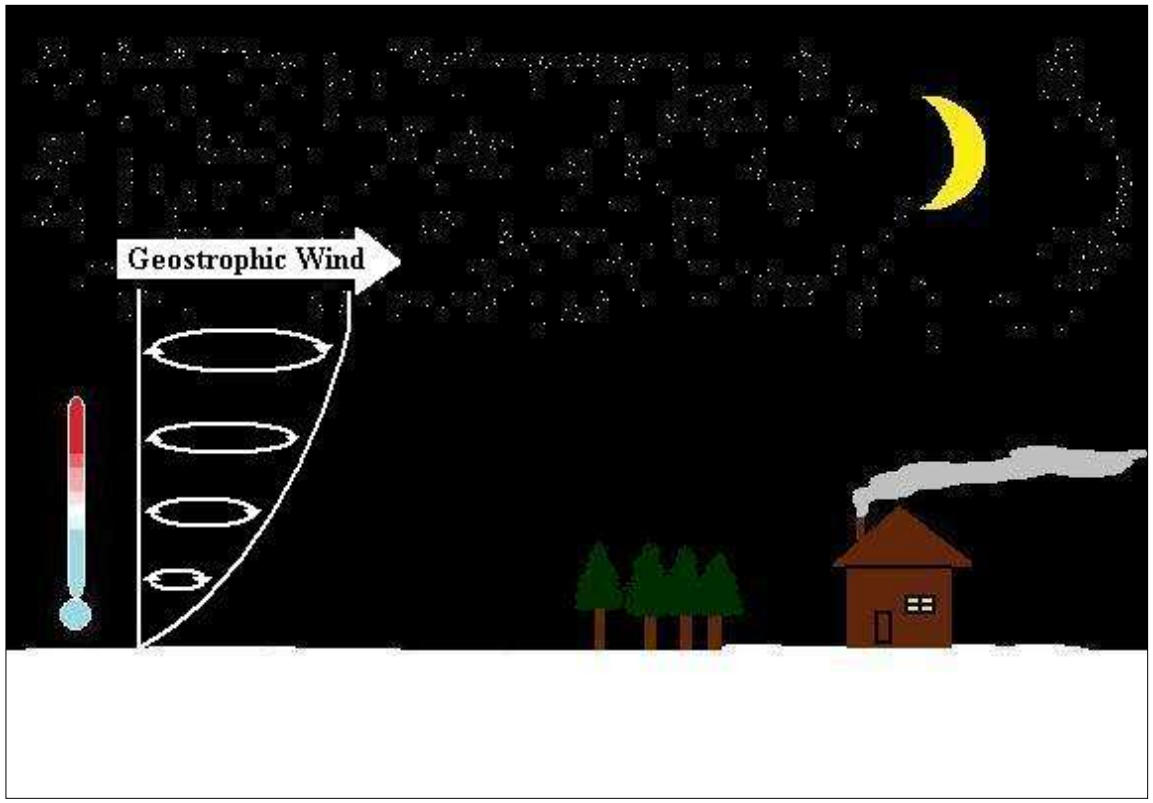

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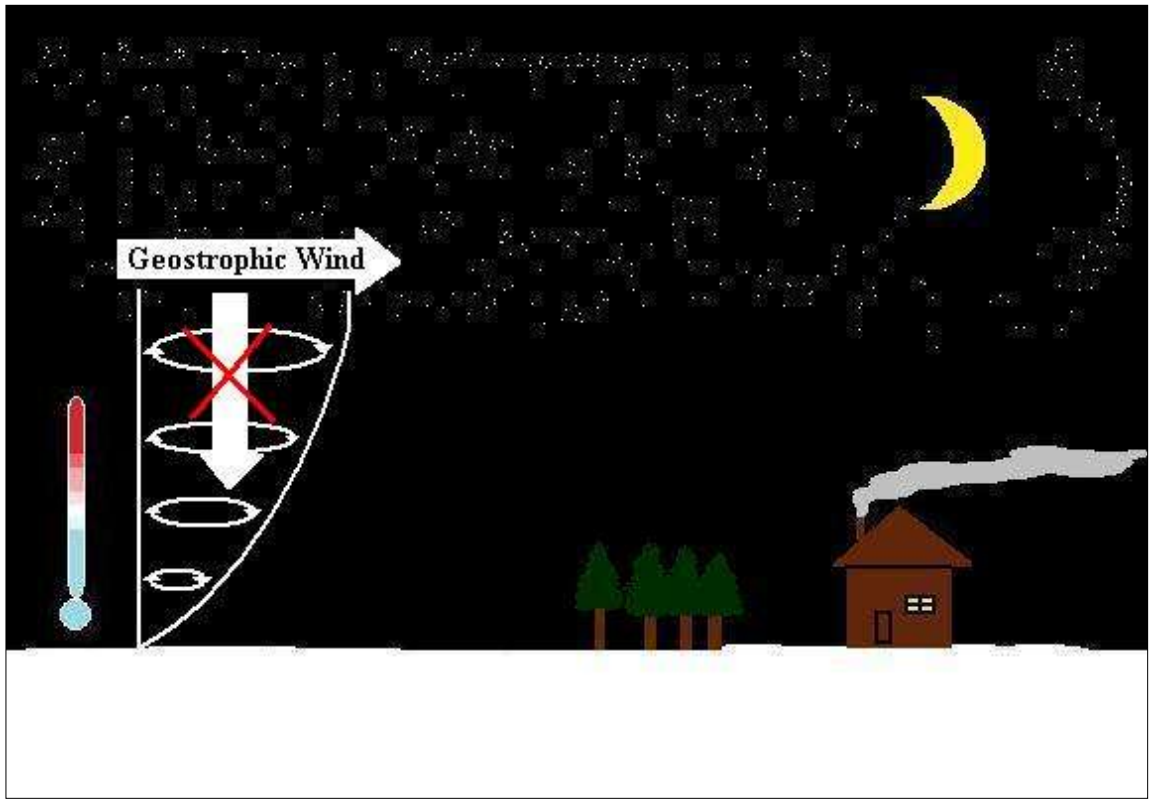
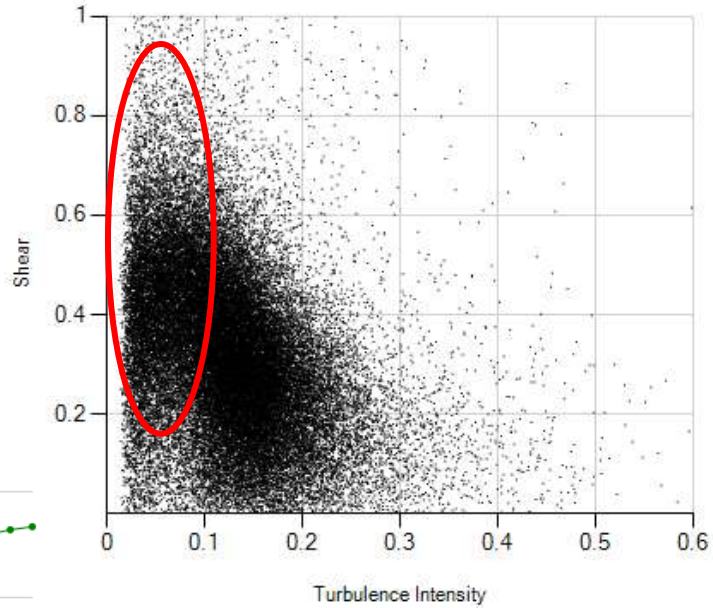
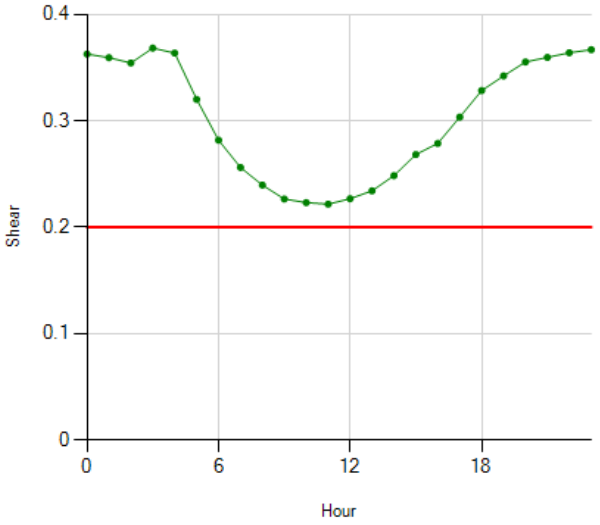
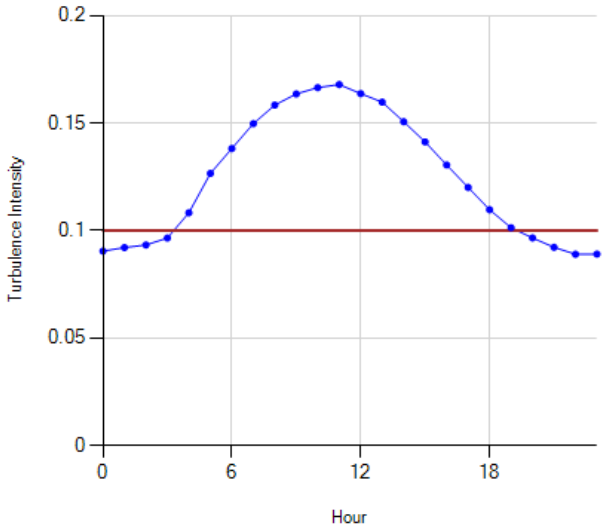


High frequency of stable atmosphere and wind conditions



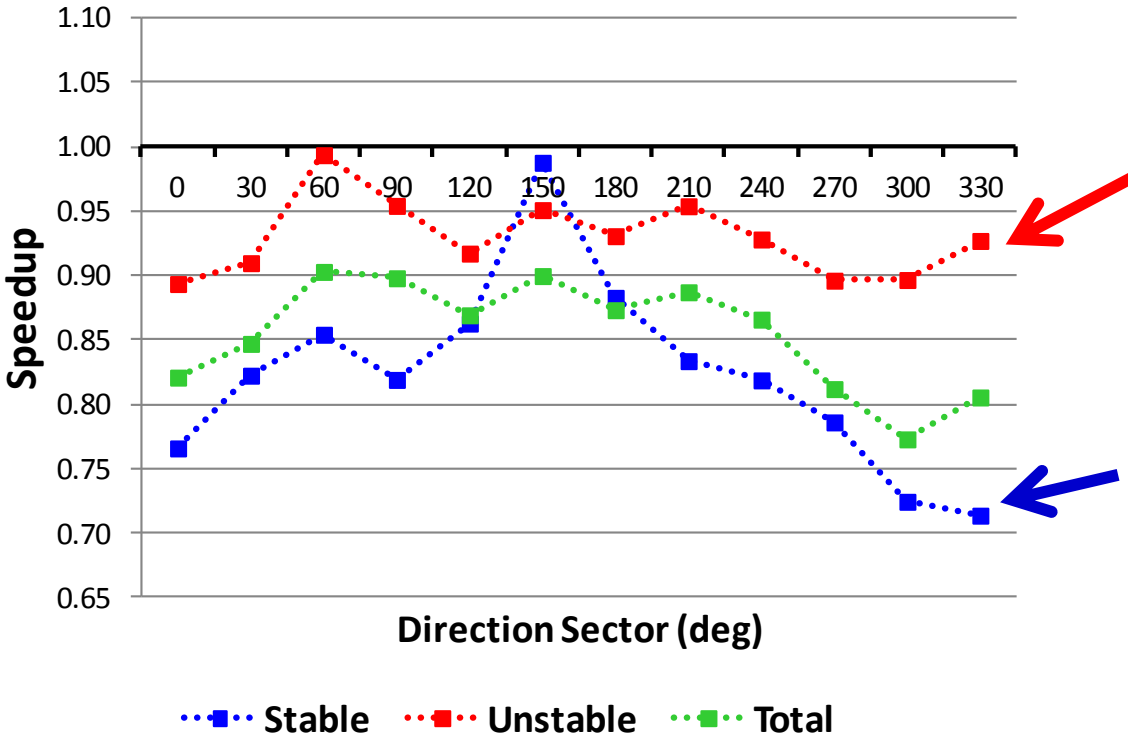


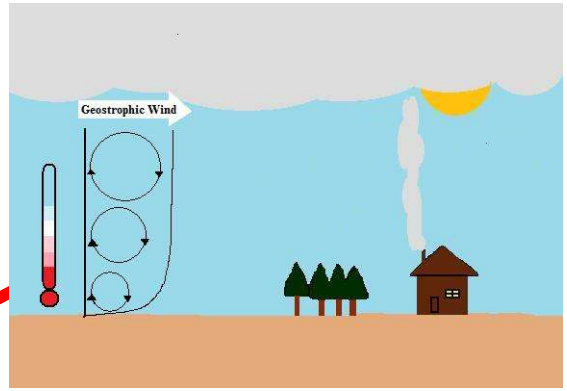
Low TI as a proxy for stable atmospheric conditions

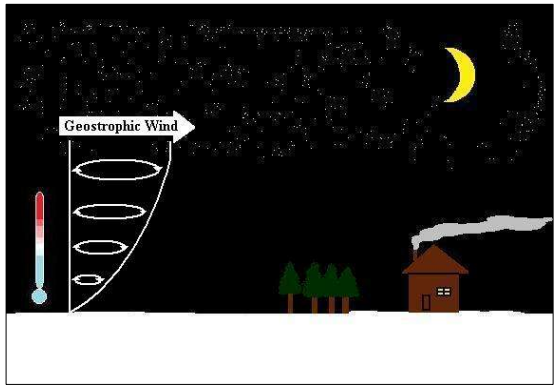


Wind Flow modelling challenges

Wind speed at mast A/Wind speed at mast B = Speedup







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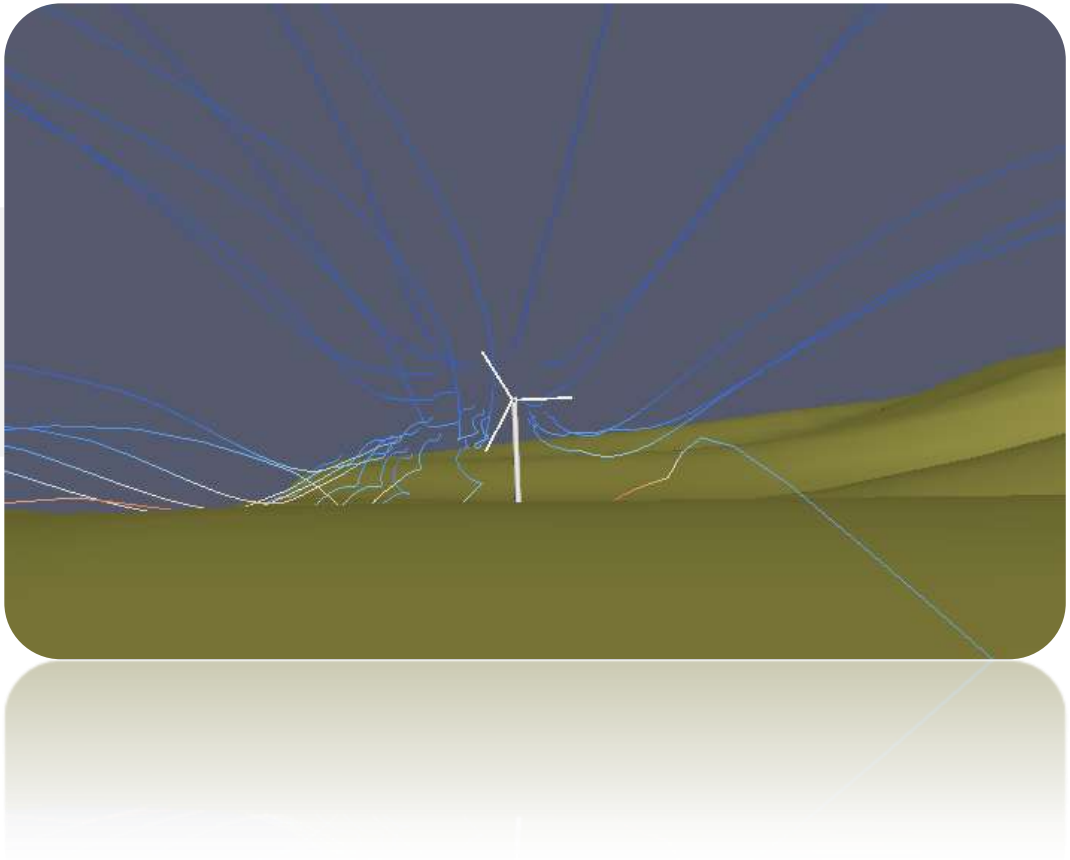
Complex CFD flow modelling for stable wind flow challenges



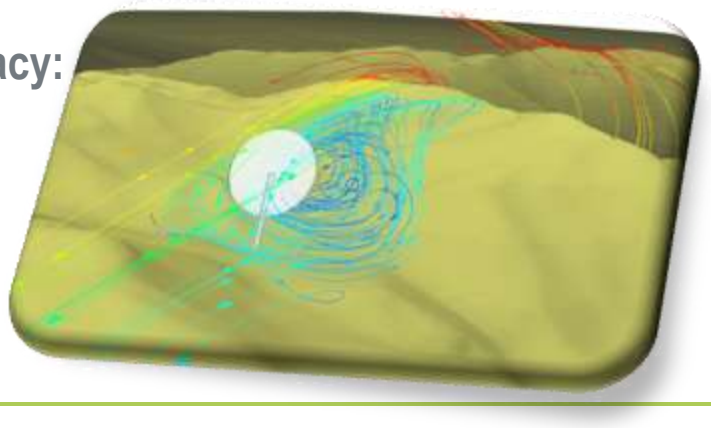
What is CFD (Computational Fluid Dynamics)

- Most accurate description of wind flow: Navier-Stokes Equations (below)
- Very difficult to solve!

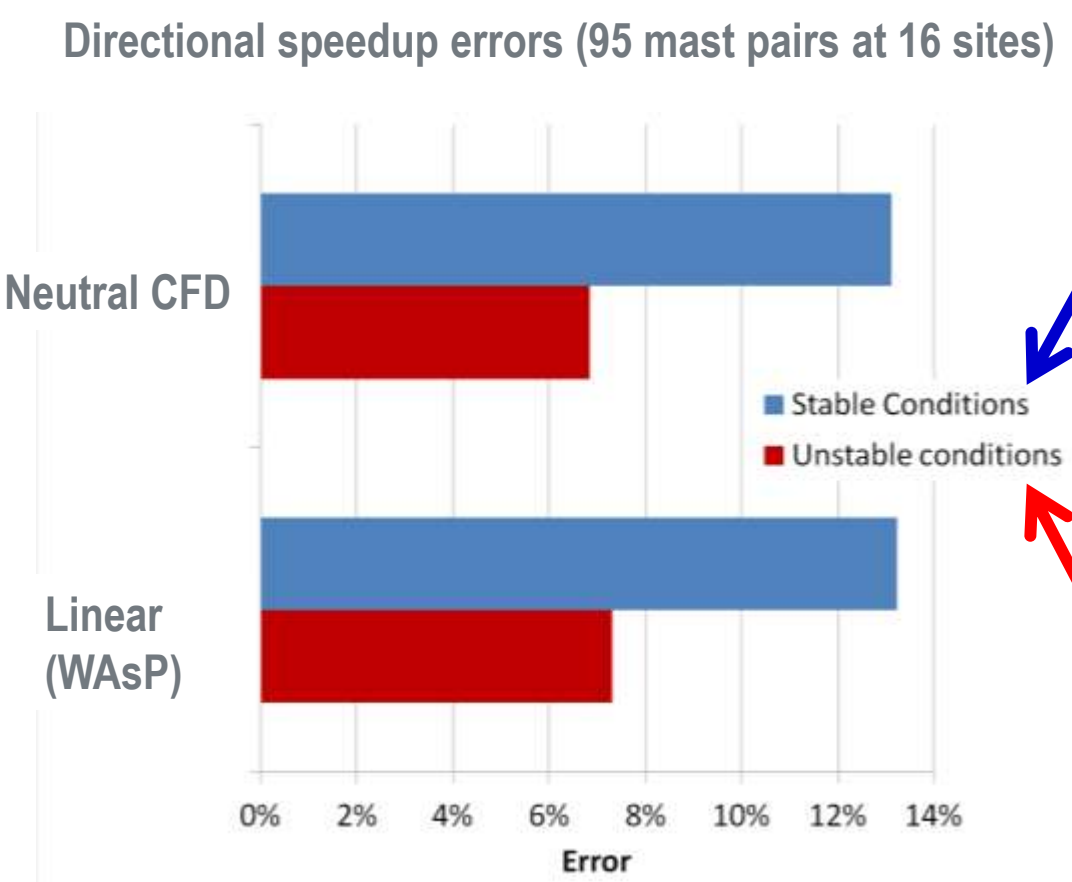
$$\overbrace{\rho\left(\underbrace{\frac{\partial \mathbf{v}}{\partial t}}_{\text{Unsteady acceleration}} + \underbrace{\mathbf{v}\cdot\nabla\mathbf{v}}_{\text{Convective acceleration}}\right)}^{\text{Inertia (per volume)}} = \overbrace{\underbrace{-\nabla p}_{\text{Pressure gradient}} + \underbrace{\mu\nabla^2\mathbf{v}}_{\text{Viscosity}}}^{\text{Divergence of stress}} + \underbrace{\mathbf{f}}_{\text{Other body forces}}$$

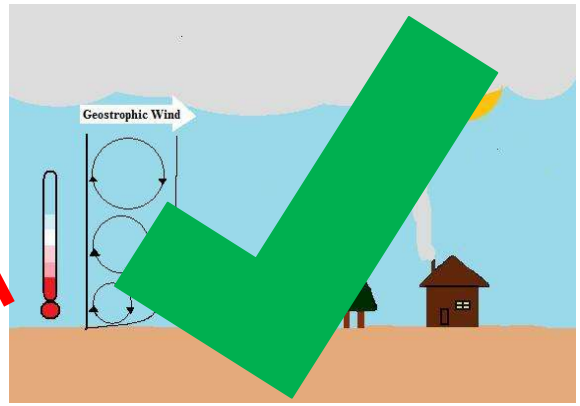
- Linear models simplify this equation - some accuracy is sacrificed

- CFD makes fewer changes – less loss of accuracy:
  - Reynolds-Average Navier-Stokes (RANS)
  - Advanced software required
  - Modern computing power required
  - Like a wind tunnel on your computer



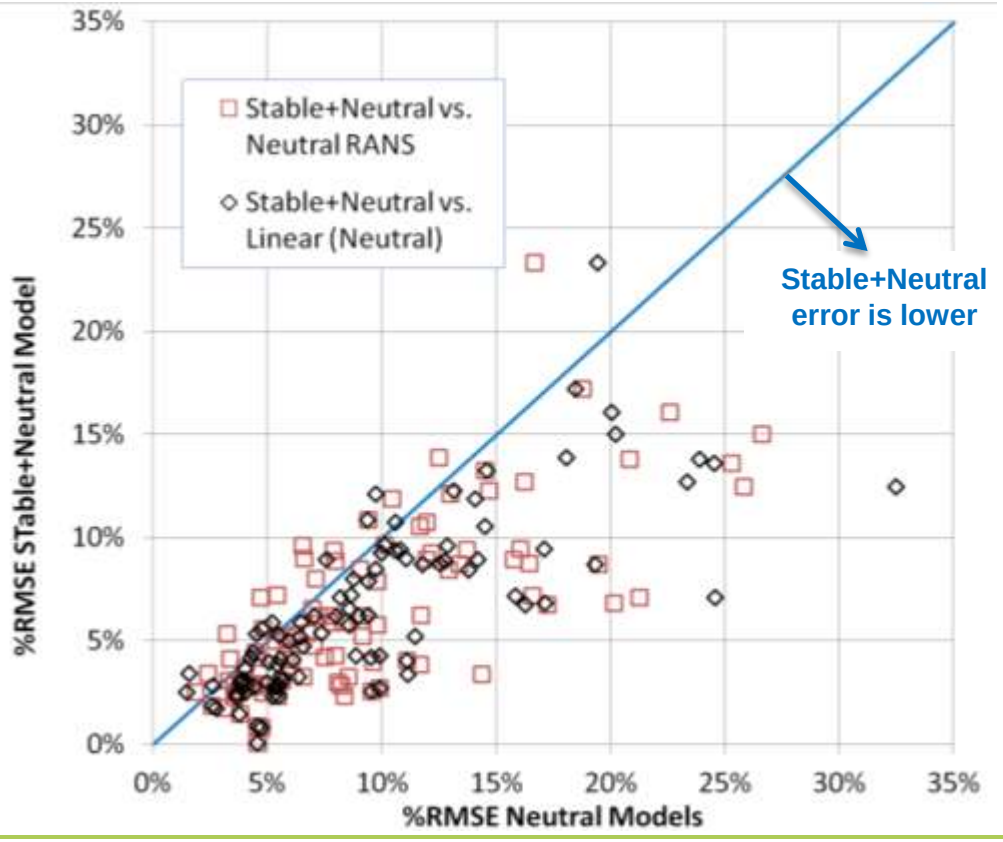
Wind Flow modelling under stable conditions





Stable + Neutral CFD approach (GL GH approach)

Directional speedup errors (95 mast pairs at 16 sites)



Average Errors

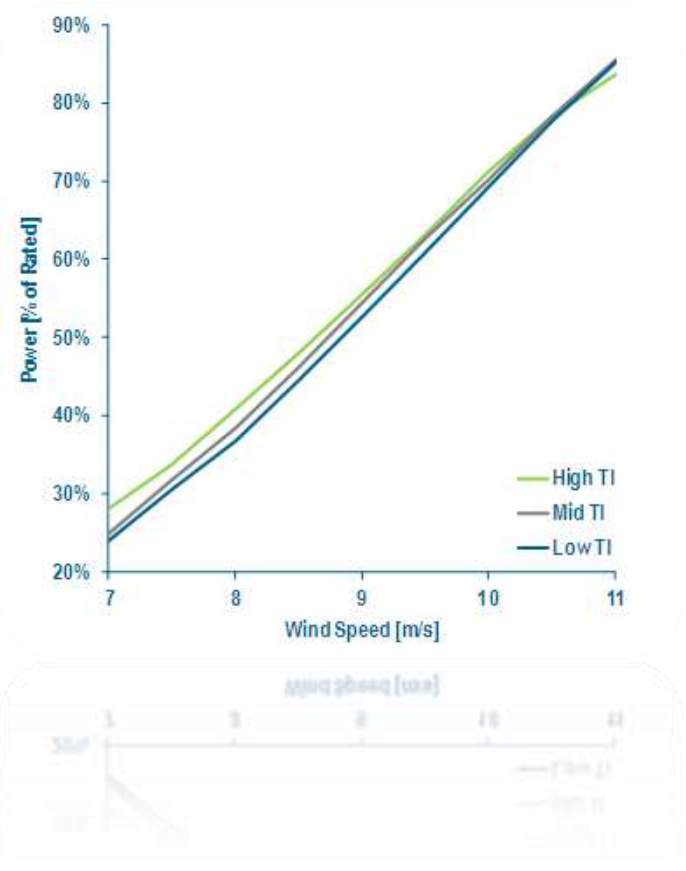
Linear (WAsP) = 9.6%

Neutral CFD = 9.5%

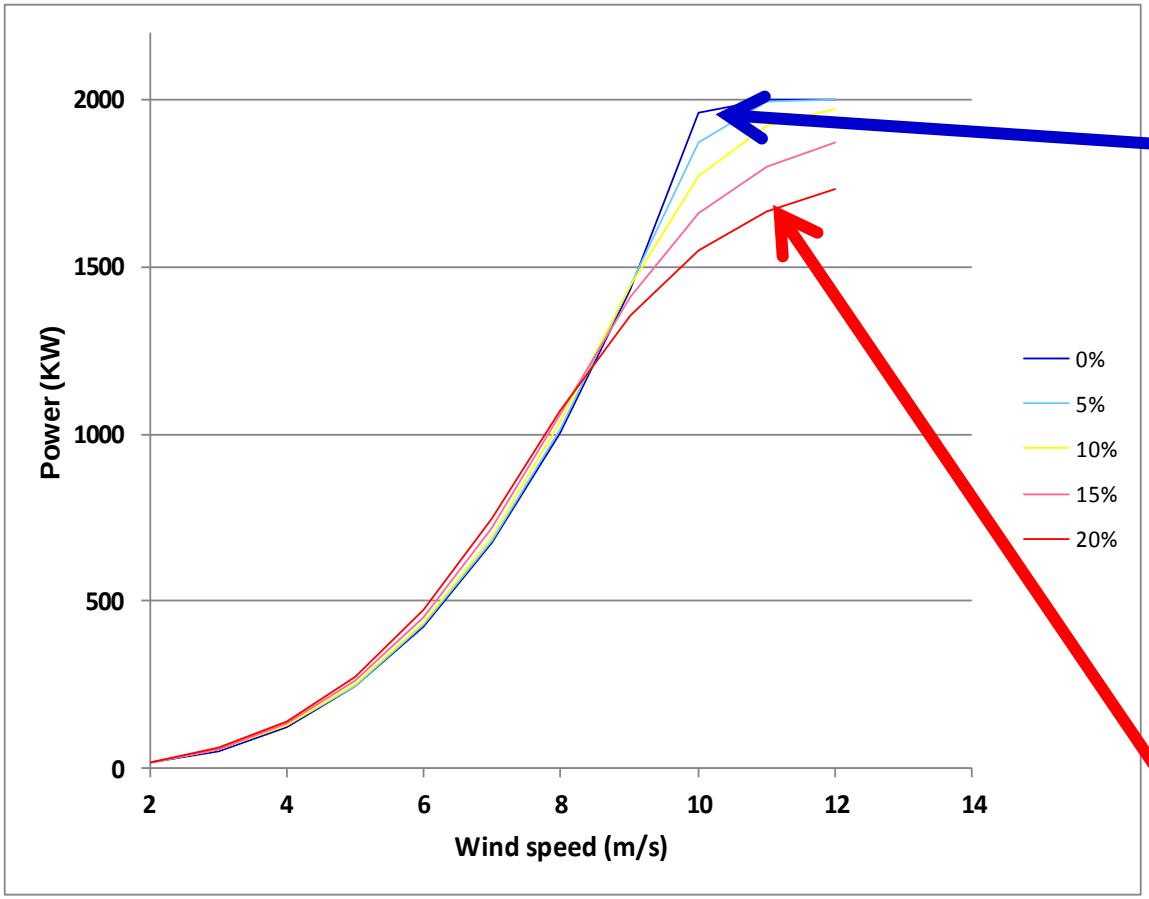
Stable + Neutral (CFD) = 6.6%

1– 2 –**3**

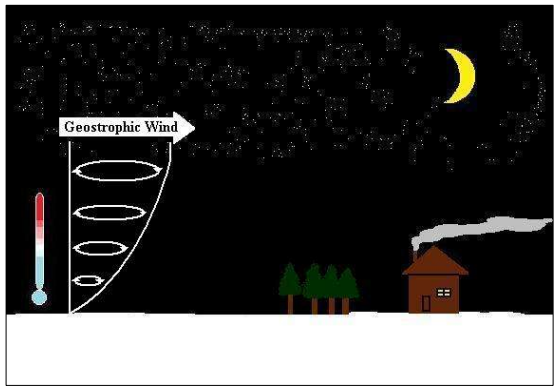
High frequency of stable conditions and turbine performance

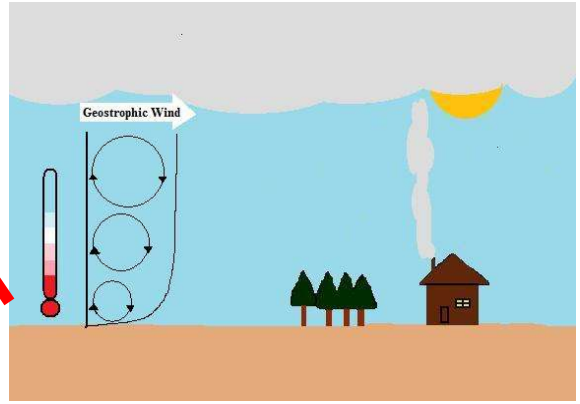


Performance of wind turbines under stable conditions in the Nordic Region – What the theory suggests



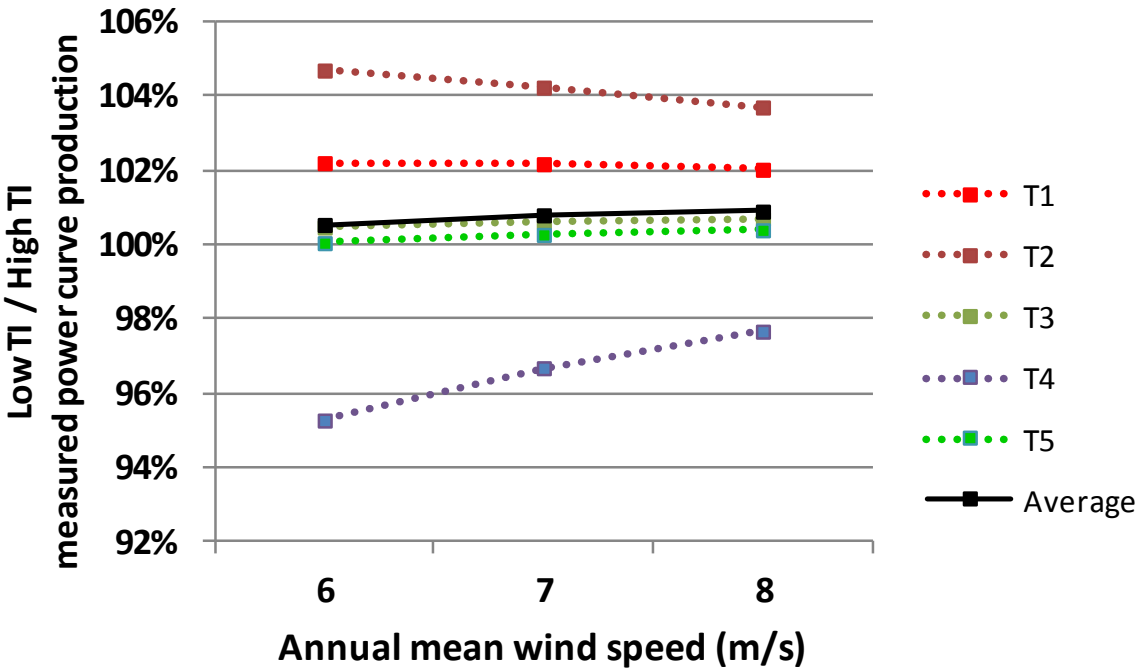
$$P = 1/2\rho(u)^3(1+\beta TI^4)ACp$$





Performance of wind turbines under stable conditions in the Nordic Region

Results for IEC Power Curve Measurements of 5 mast/turbine pairs in Sweden



No partial icing cleaning and no temperature filtering

Performance of wind turbines under stable conditions in the Nordic Region

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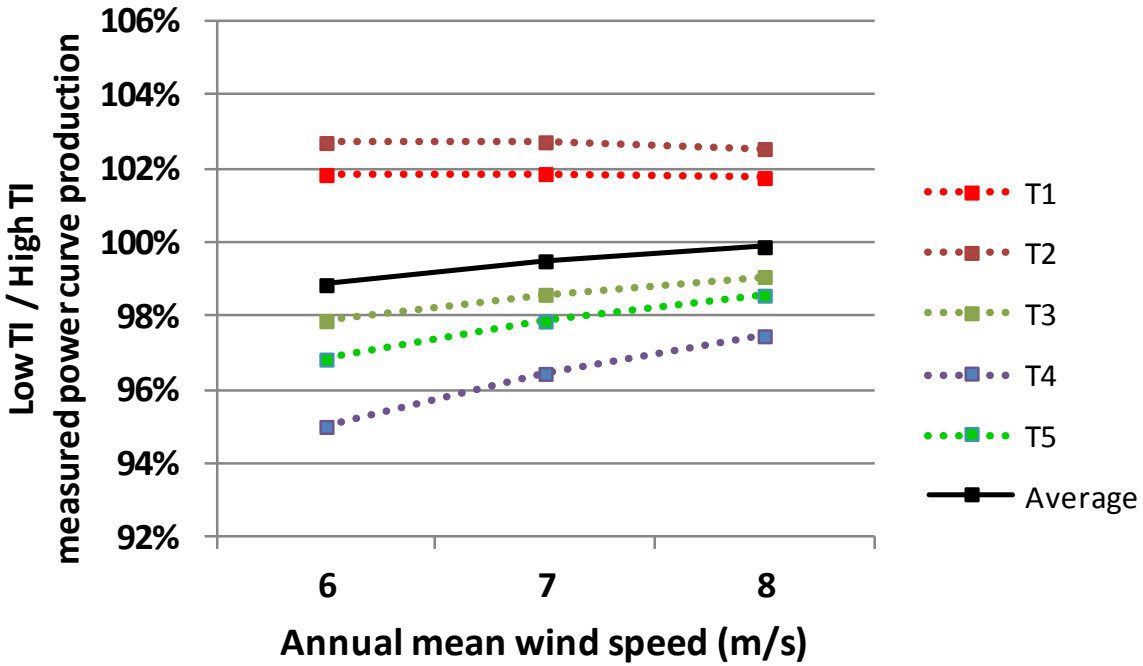

Data cleaned for partial icing and filtered excluding temperatures below 0˚C

Performance of wind turbines under stable conditions in the Nordic Region

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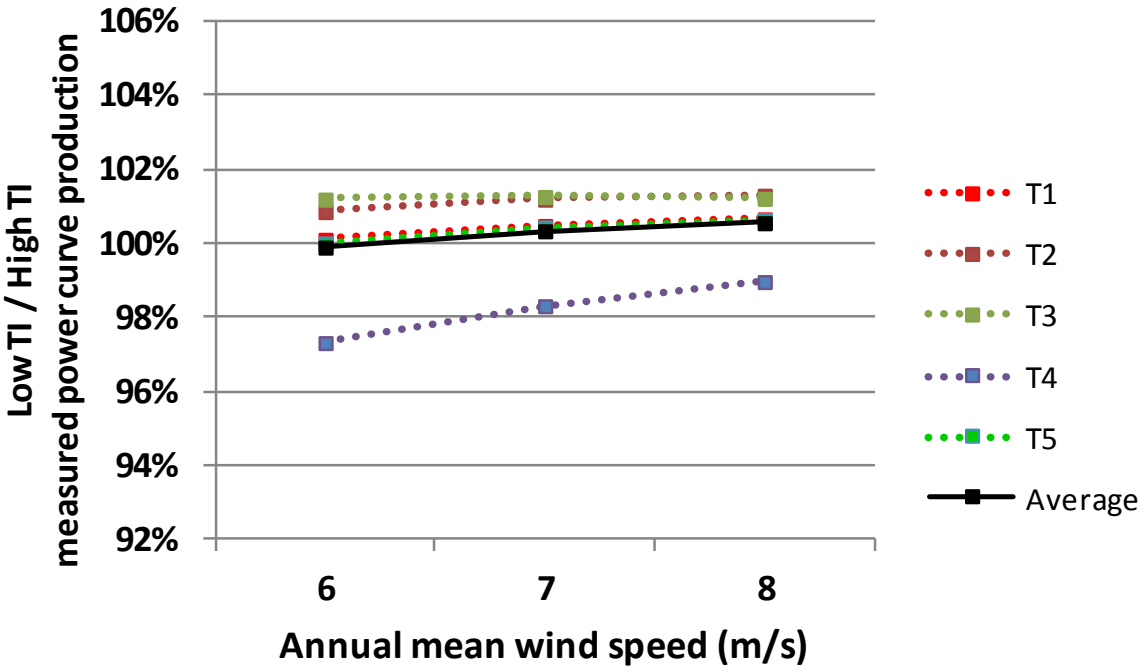
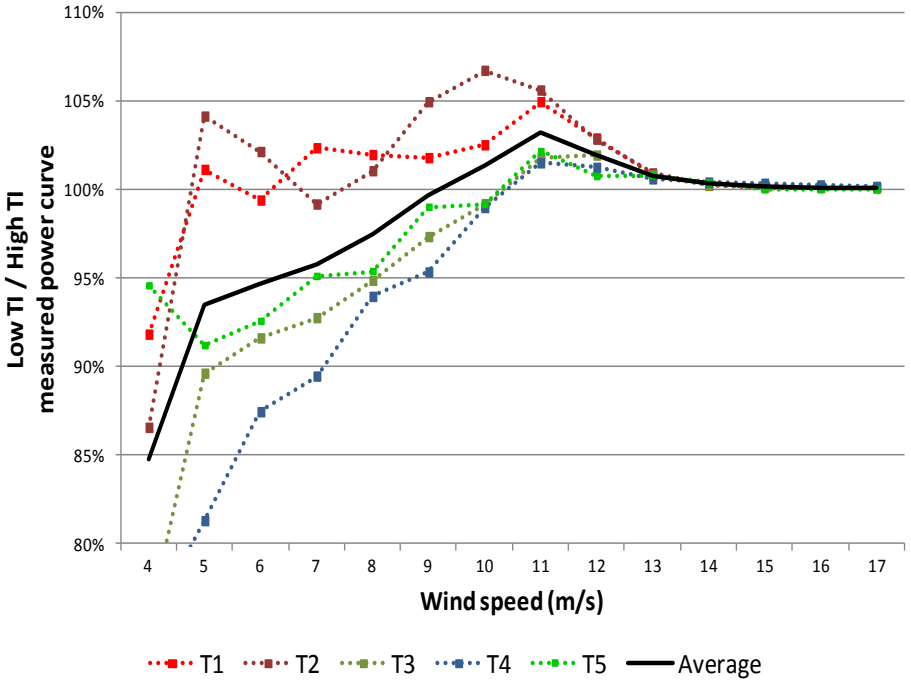


Data cleaned for partial icing and filtered excluding temperatures below 0˚C and different site calibration speedups applied for stable and unstable conditions

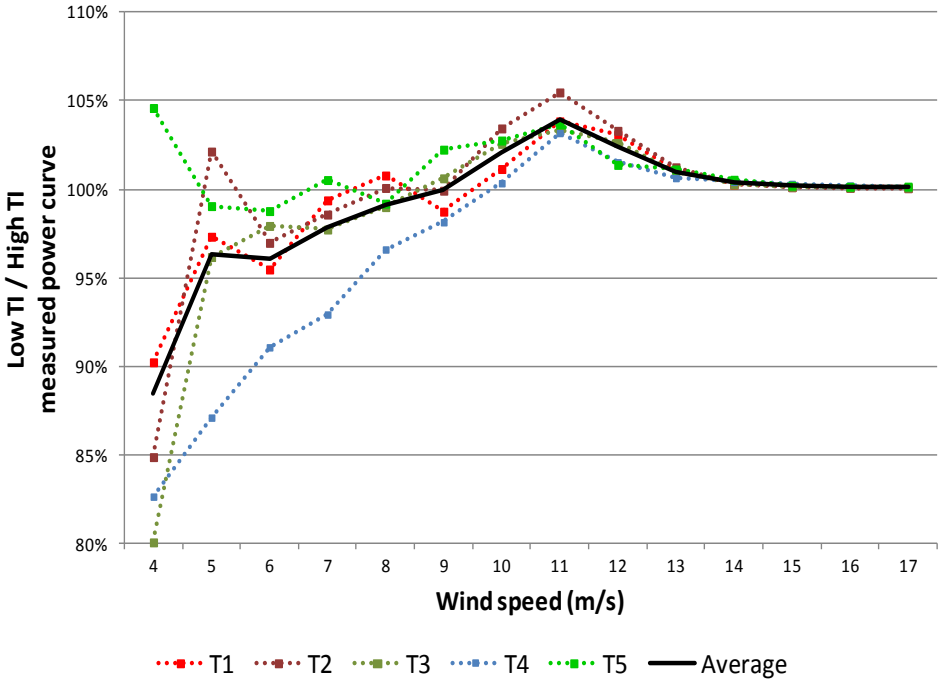
Performance of wind turbines under stable conditions in the Nordic Region

Results for IEC Power Curve Measurements of 5 mast/turbine pairs in Sweden

Without different site calibration speedups



With different site calibration speedups



Conclusions

- There is high frequency of stable and very stable atmospheric conditions in sites across the Nordic Region caused by radiative cooling
- This presents a challenge for both wind flow modelling and turbine performance
- Stable CFD reduces the error in wind flow modelling at these sites
- Theory shows that low turbulence reduces turbine performance in raising part of the power curve
- Preliminary Nordic data supports this, however shows recovery in the “knee” of the power curve
- Need to gather more Power Curve Measurement data across the Nordic region
- Careful consideration should be given to winter Power Curve Measurement data, as partial icing affects more low TI data than high TI, and the anemometry used
- Site calibration speedups for stable and unstable conditions should be considered separately as suggested by the new draft of the IEC standard

Thank you

Any questions?

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With Thanks to:
Simon Cox
Bob Hodgetts
Andrew Tindal
GL GH CFD Team
GL GH AMOS Team