DNV GL – ENERGY – RENEWABLES ADVISORY

The State of the Art in Energy Assessments

Making the Business Case

Mark Purcell

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Introduction

- DNV GL formerly Garrad Hassan
  - The world's largest dedicated renewable energy consultancy.
  - Independent technical and engineering services, software products and training in onshore and offshore wind, wave and tidal and solar PV and CSP.
  - Now a part of DNV GL after a recent merger, bringing together over 3,000 energy experts world wide

- Mark Purcell
  - Engineer within the Energy and Development Services team.
  - Joined Garrad Hassan in 2011 in Melbourne, Australia.
  - Regional specialist for Computational Fluid Dynamics and Virtual Met Data in Asia-Pacific.

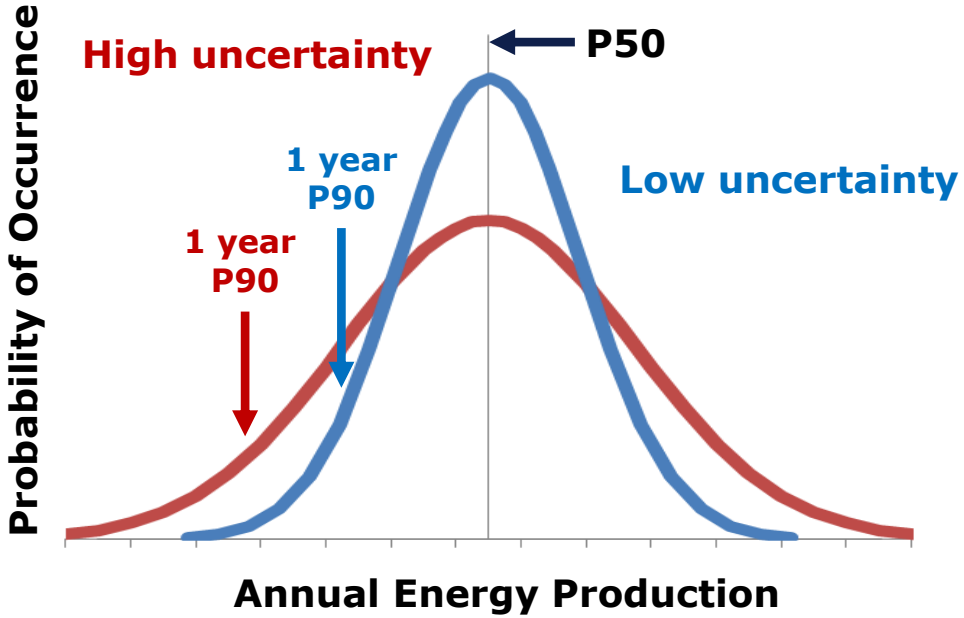
Outline

- Introduction
- Uncertainty
- Long term adjustments
  - Mesoscale downscaling
- Wind flow modelling
  - Computational Fluid Dynamics
- Conclusion

Uncertainty

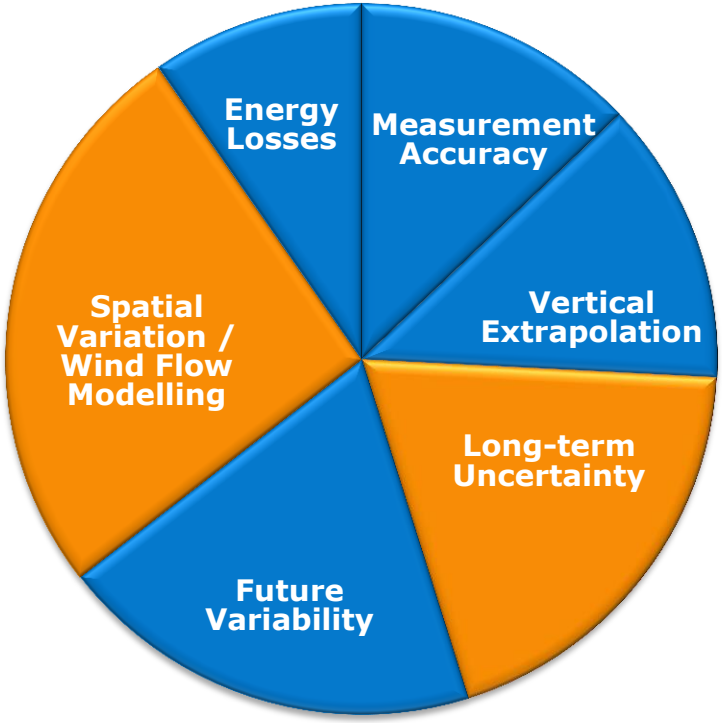
- Financier's models often size debt on the P90 10-year energy case
- Financier will opt for an uncertainty level in the Base case with an appropriate Debt Service Cover Ratio (DSCR) depending on the perceived risk involved
- DSCR =

$$\frac{\text{Wind farm earnings to service the debt}}{\text{Annual debt service on the loan}}$$



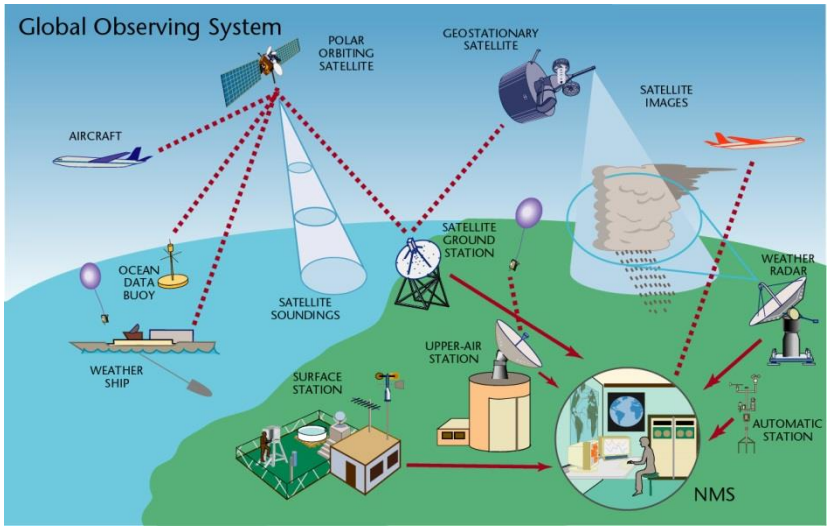
Uncertainty

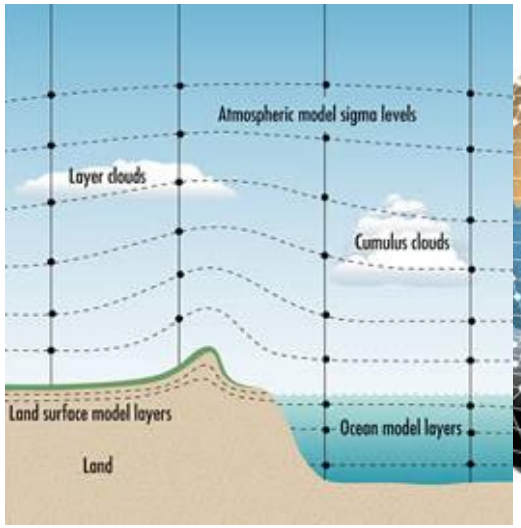
- Typical uncertainties accounted for in an Energy Yield Assessment



Long term adjustments

- Reanalysis products
  - Gridded reconstructions of historical weather conditions.
  - Make use of numerical weather prediction models in combination with data assimilation techniques to ingest all available historical meteorological and sea surface measurements





Long term adjustments

- What is mesoscale downscaling?
- Sophisticated numerical weather prediction system designed to represent weather features such as sea breezes, slope-valley flows, on up to hurricanes
- Weather Research and Forecasting (WRF) model

Primitive equations solved by WRF

$$\frac{\partial u}{\partial t} = -u\frac{\partial u}{\partial x} - v\frac{\partial u}{\partial y} - w\frac{\partial u}{\partial z} + \frac{uv\tan\phi}{a} - \frac{uw}{a} - \frac{1}{\rho}\frac{\partial p}{\partial x} - 2\Omega(w\cos\phi - v\sin\phi) + Fr_x$$

$$\frac{\partial v}{\partial t} = -u\frac{\partial v}{\partial x} - v\frac{\partial v}{\partial y} - w\frac{\partial v}{\partial z} - \frac{u^2\tan\phi}{a} - \frac{uw}{a} - \frac{1}{\rho}\frac{\partial p}{\partial y} - 2\Omega u\sin\phi + Fr_y$$

$$\frac{\partial w}{\partial t} = -u\frac{\partial w}{\partial x} - v\frac{\partial w}{\partial y} - w\frac{\partial w}{\partial z} - \frac{u^2+v^2}{a} - \frac{1}{\rho}\frac{\partial p}{\partial z} + 2\Omega u\cos\phi - g + Fr_z$$

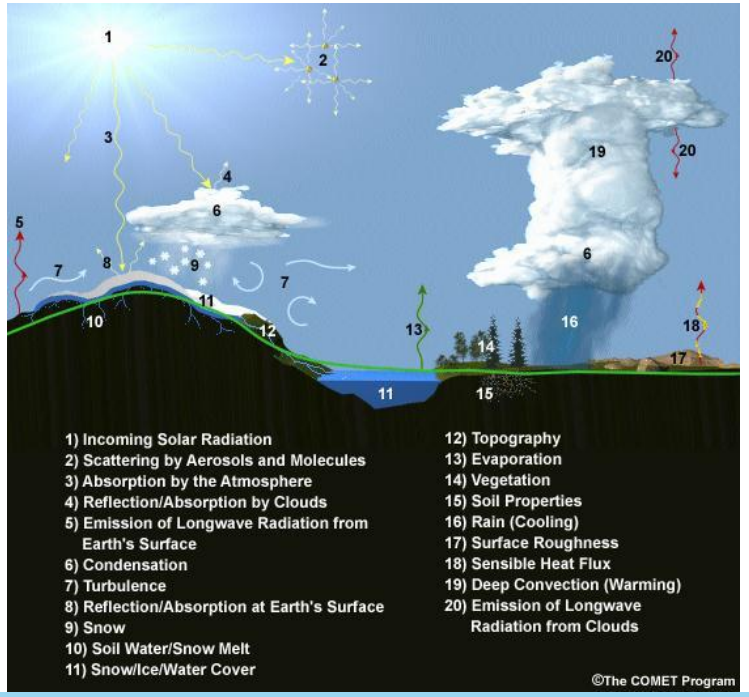
$$\frac{\partial T}{\partial t} = -u\frac{\partial T}{\partial x} - v\frac{\partial T}{\partial y} + (\gamma - \gamma_d)w + \frac{1}{c_p}\frac{dH}{dt}$$

$$\frac{\partial \rho}{\partial t} = -u\frac{\partial \rho}{\partial x} - v\frac{\partial \rho}{\partial y} + -w\frac{\partial \rho}{\partial z} - \rho\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z}\right)$$

$$\frac{\partial q_v}{\partial t} = -u\frac{\partial q_v}{\partial x} - v\frac{\partial q_v}{\partial y} - w\frac{\partial q_v}{\partial z} + Q_v$$

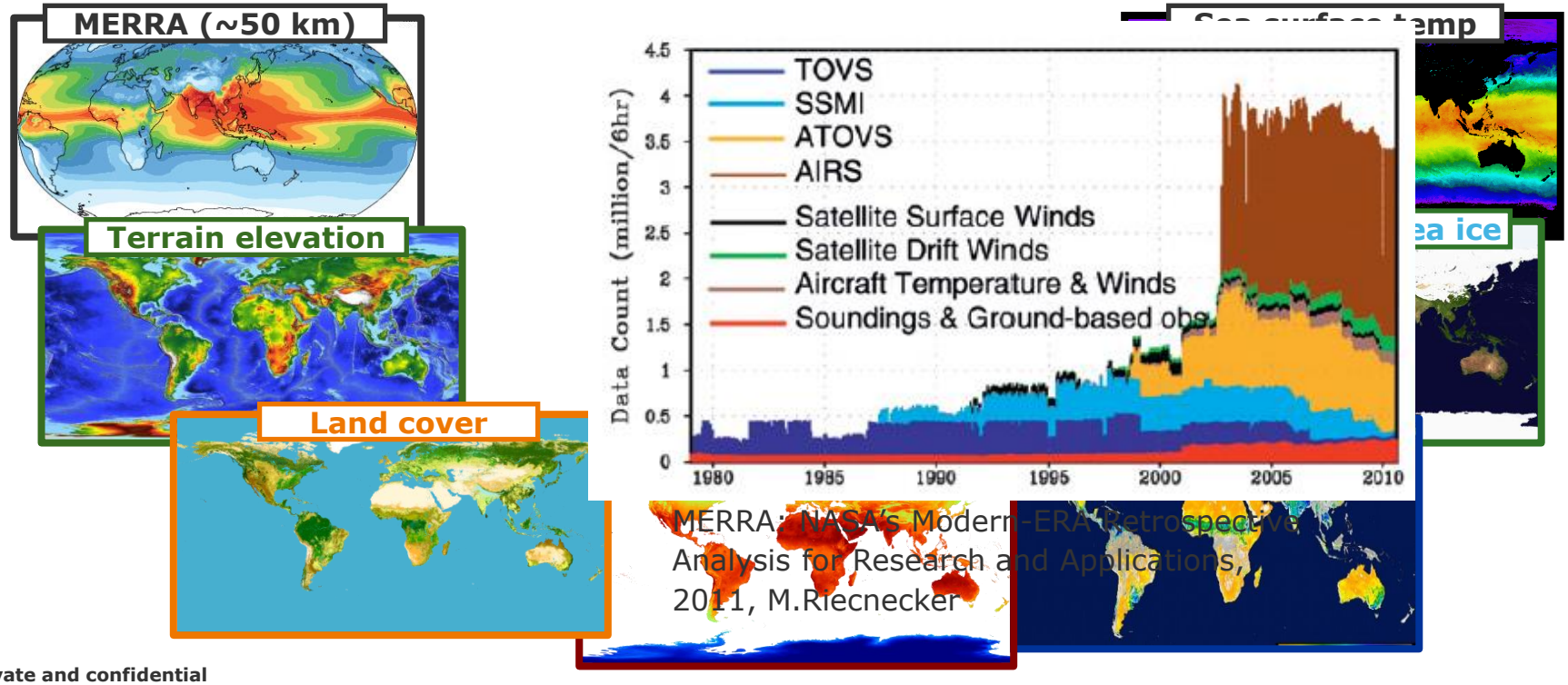
$$P = \rho RT$$

Physical processes in the WRF Model



Long term adjustments

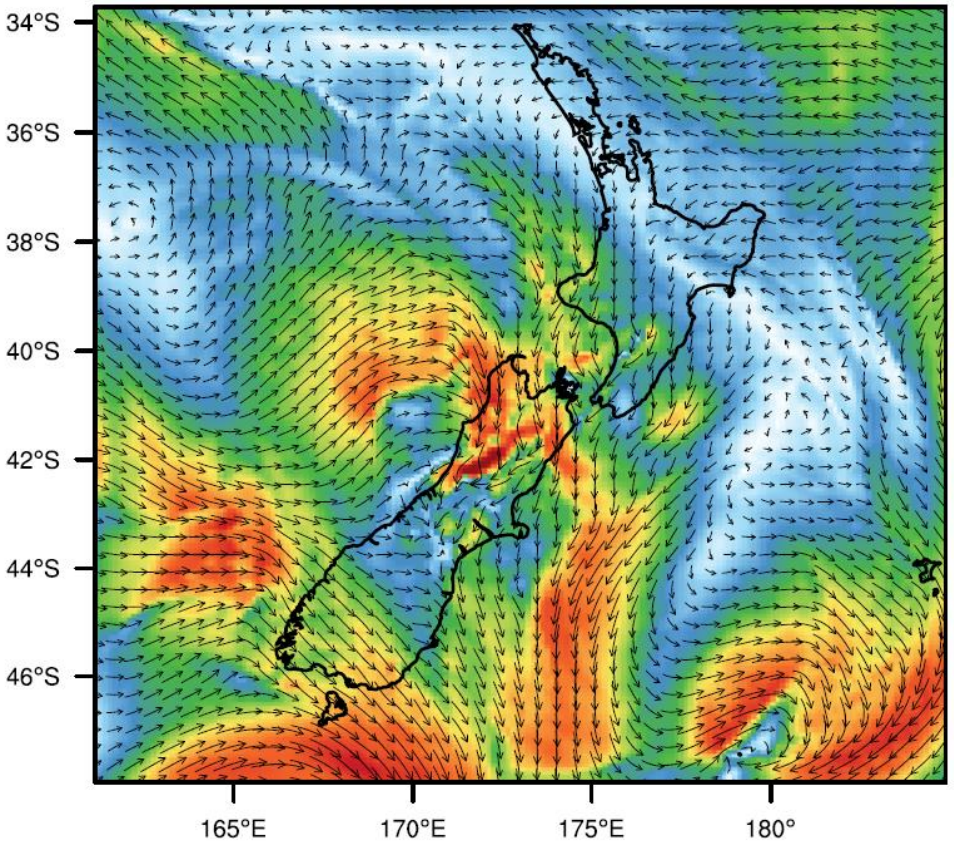
- Virtual Meteorological Data (VMD)
  - Principally based on the Weather Research and Forecasting (WRF) model.
  - High resolution long-term reference data sets for any location in the world



Long term adjustments

- Virtual Meteorological Data (VMD)

Winds at 55 m AGL red = higher wind speeds

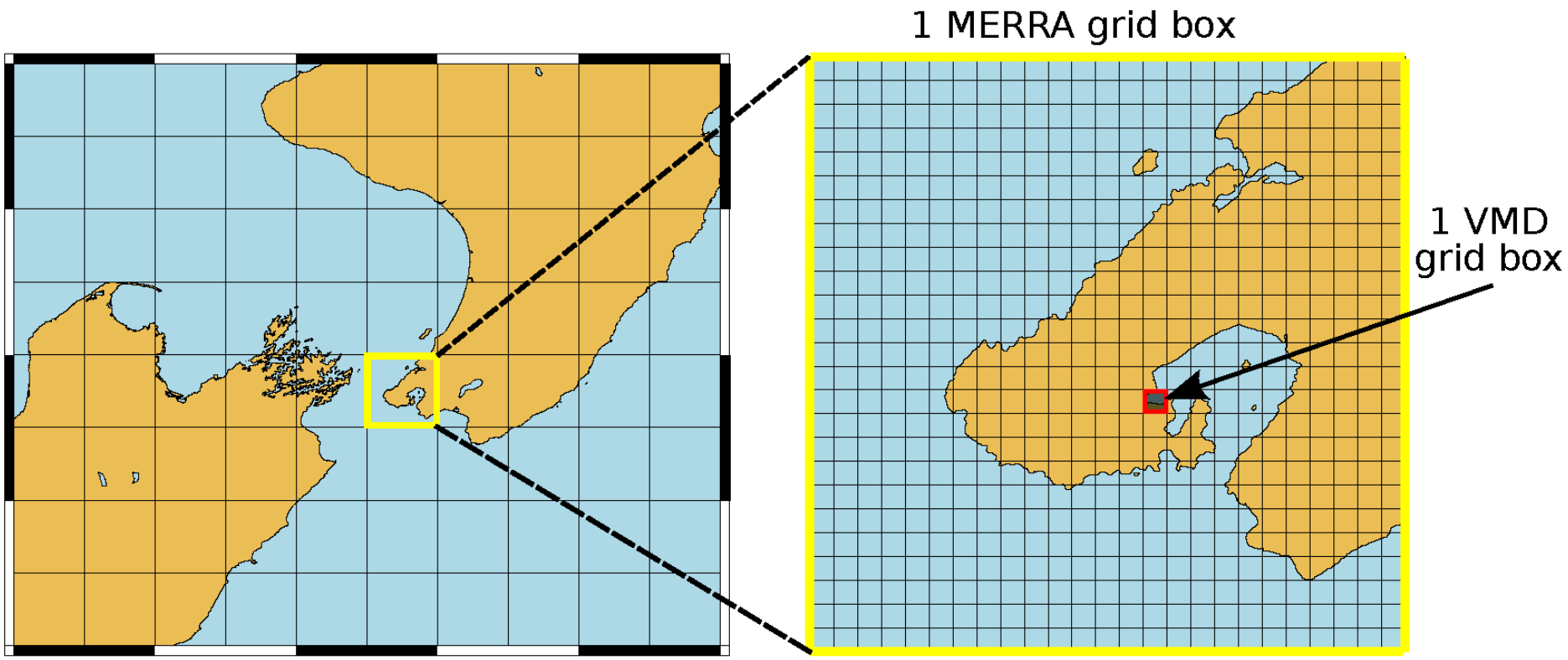


Long term adjustments

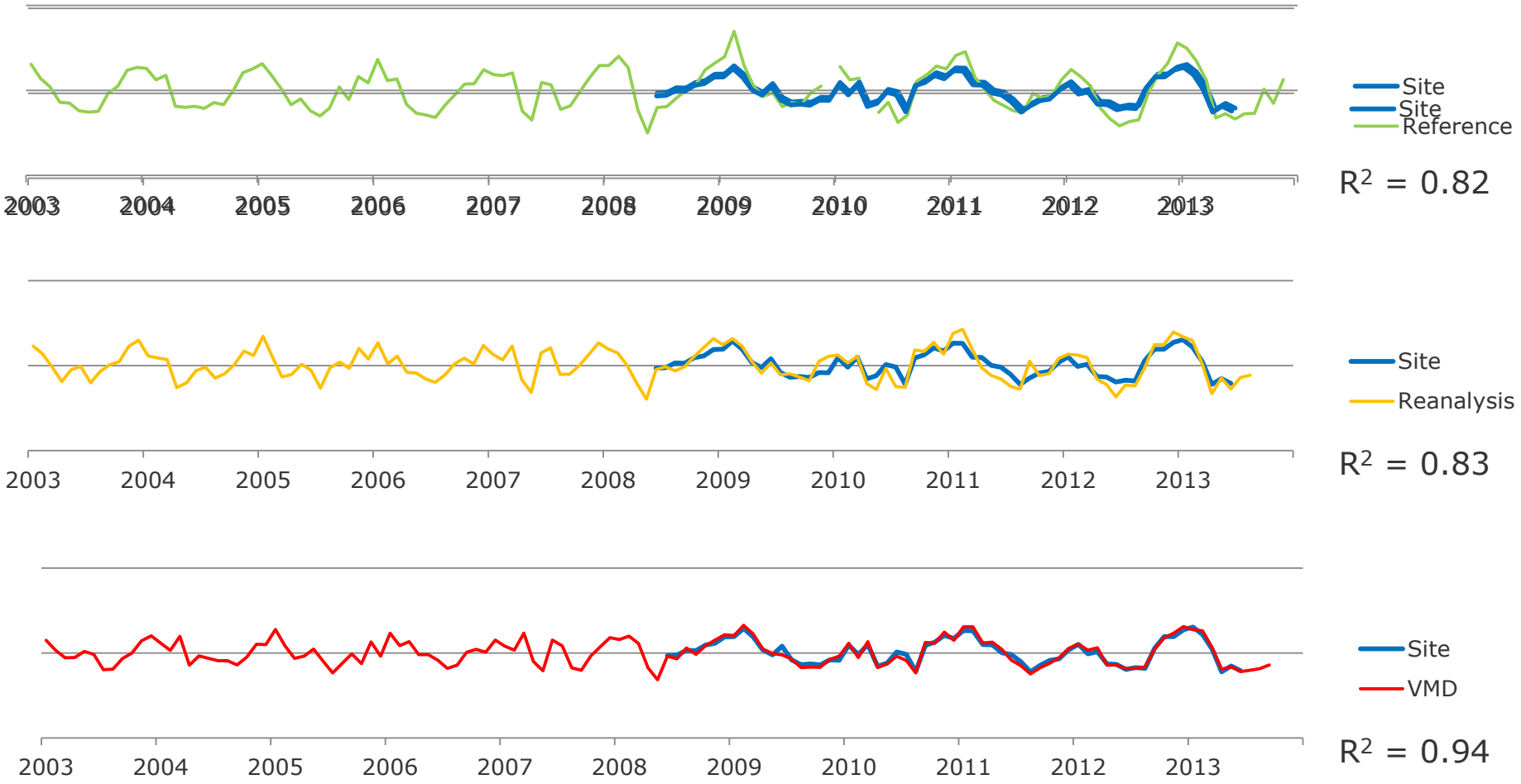
- Virtual Meteorological Data (VMD)

MERRA horizontal resolution: ~ 50 km

VMD horizontal resolution: 2 km



Long term adjustments



Long term adjustments

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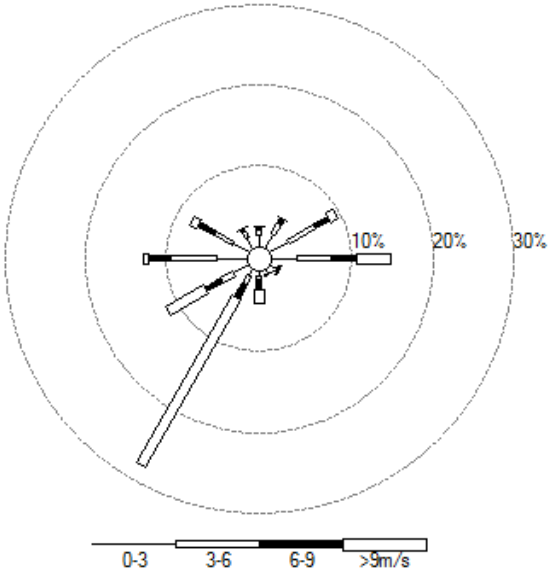
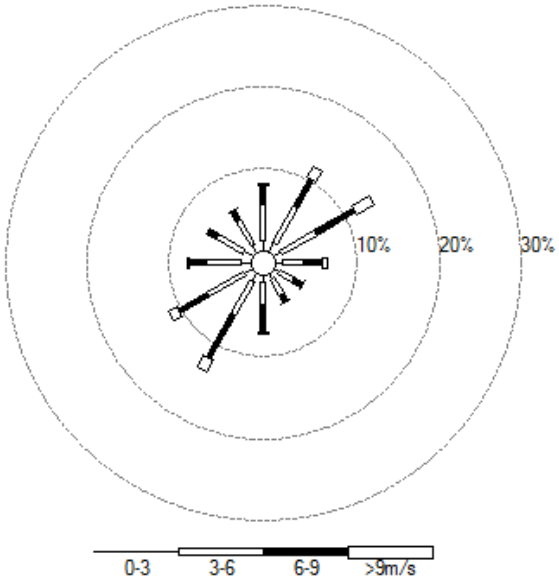
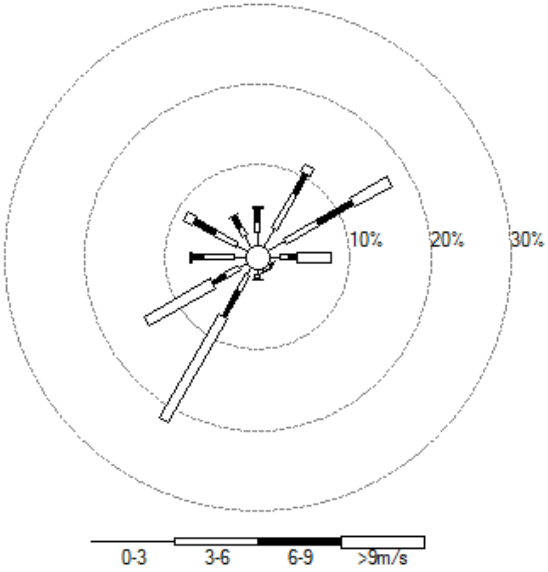


Site



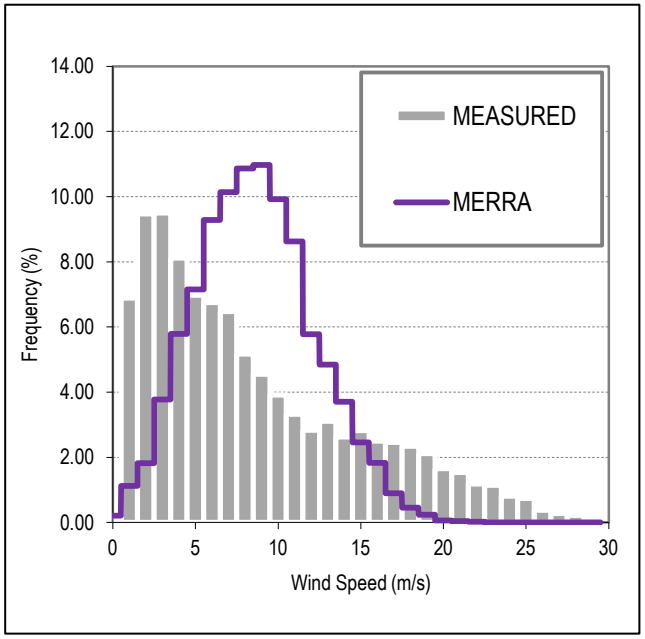
MERRA

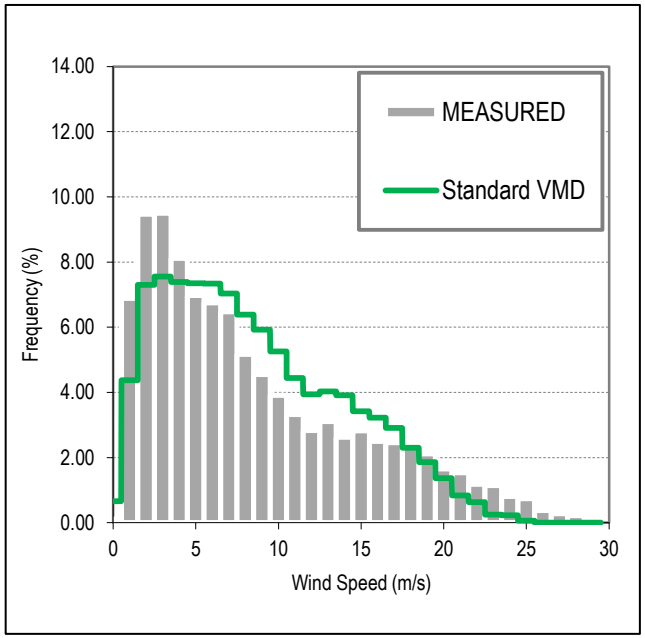


Standard VMD

Long term adjustments

- Virtual Meteorological Data (VMD)





Long term adjustments

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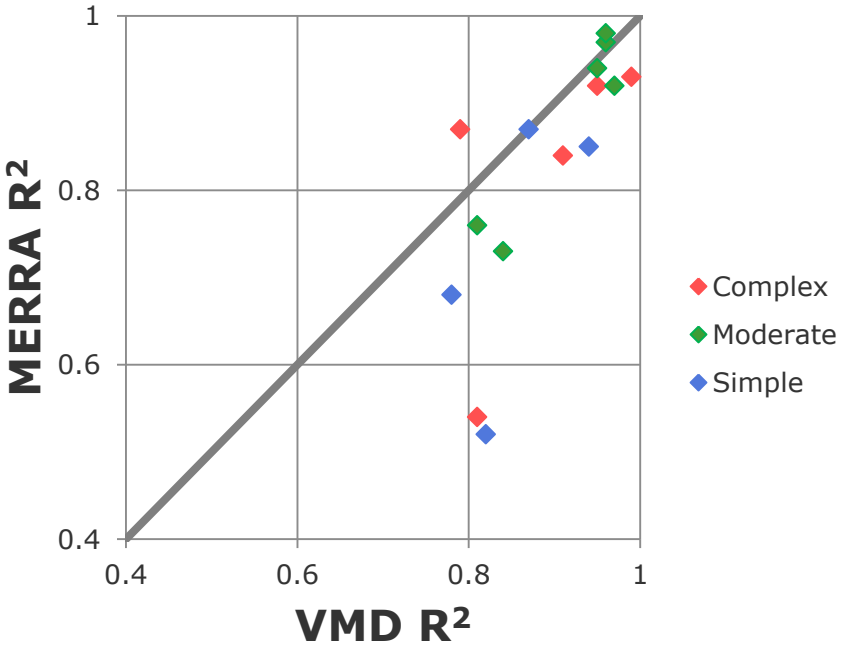
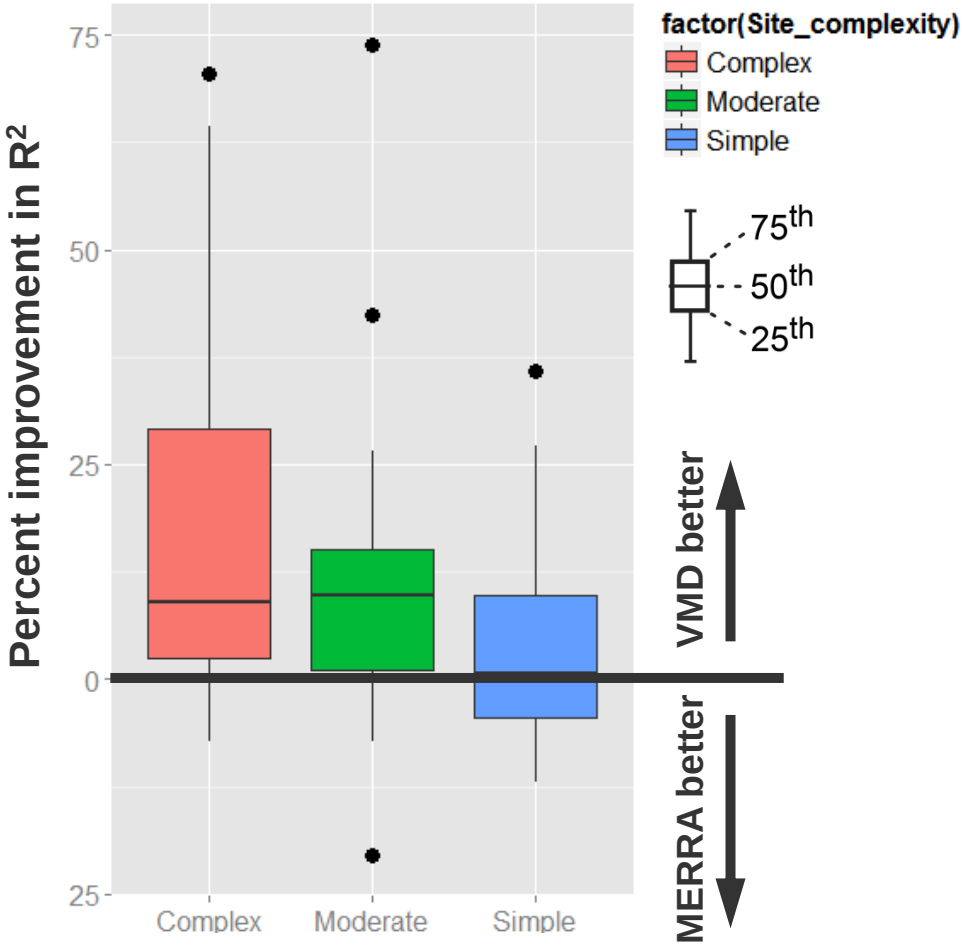
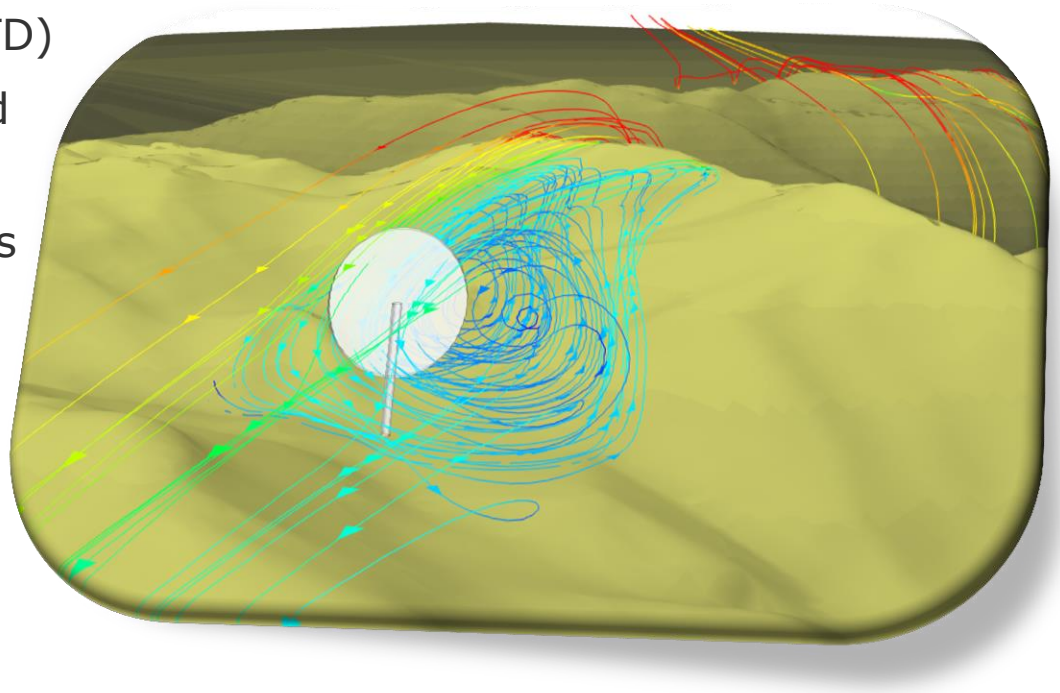




Wind flow modelling

- Linear model
  - Fast turnaround and large experience base
  - Range of validity is limited

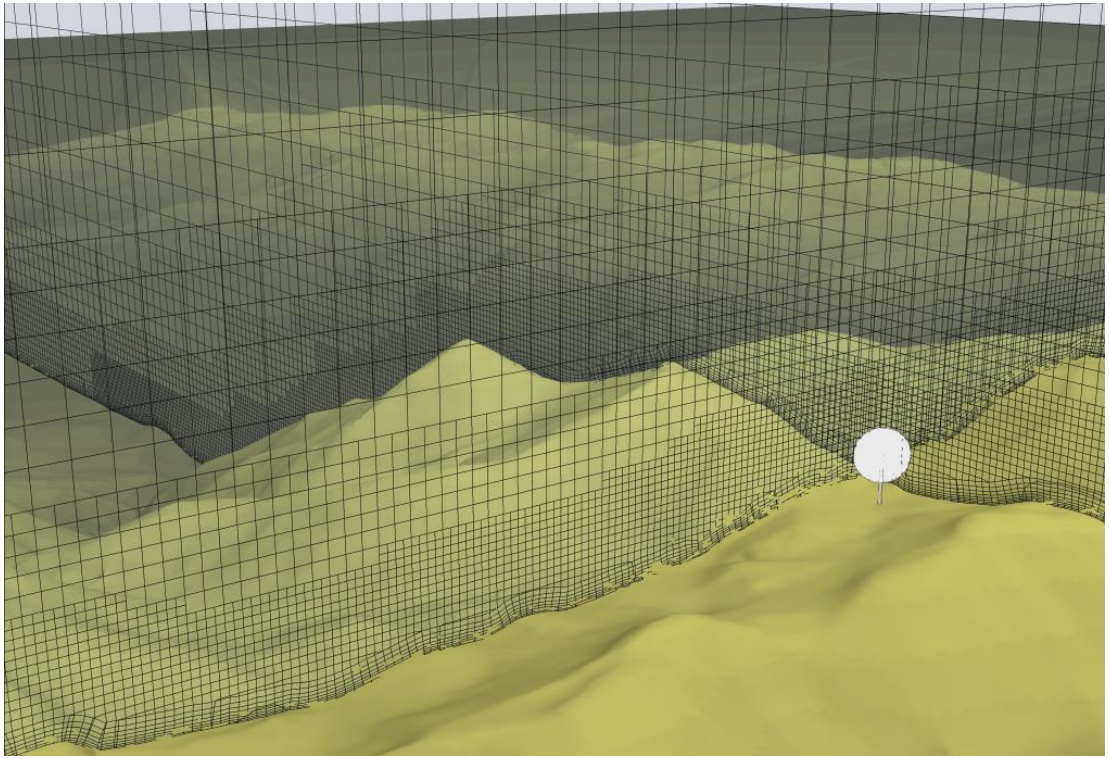
- Computational Fluid Dynamics (CFD)
  - Makes use of Reynolds Averaged Navier-Stokes equations
  - Can capture non-linear dynamics and the impact of atmospheric stability



Wind flow modelling

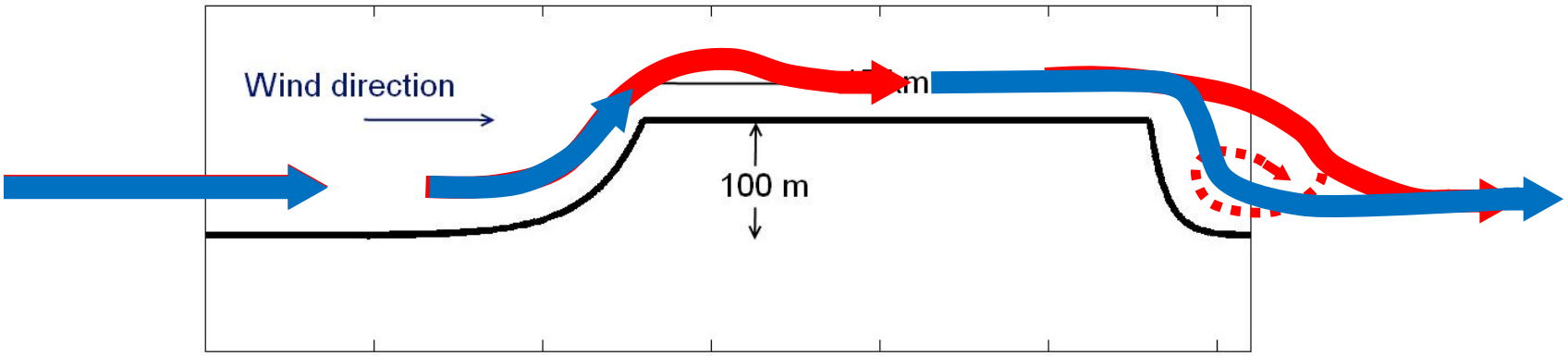
$$\overbrace{\rho\left(\underbrace{\frac{\partial \mathbf{v}}{\partial t}}_{\text{Unsteady acceleration}} + \underbrace{\mathbf{v}\cdot\nabla\mathbf{v}}_{\text{Convective acceleration}}\right)}^{\text{Inertia (per volume)}} = \overbrace{\underbrace{-\nabla p}_{\text{Pressure gradient}} + \underbrace{\mu\nabla^2\mathbf{v}}_{\text{Viscosity}}}^{\text{Divergence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

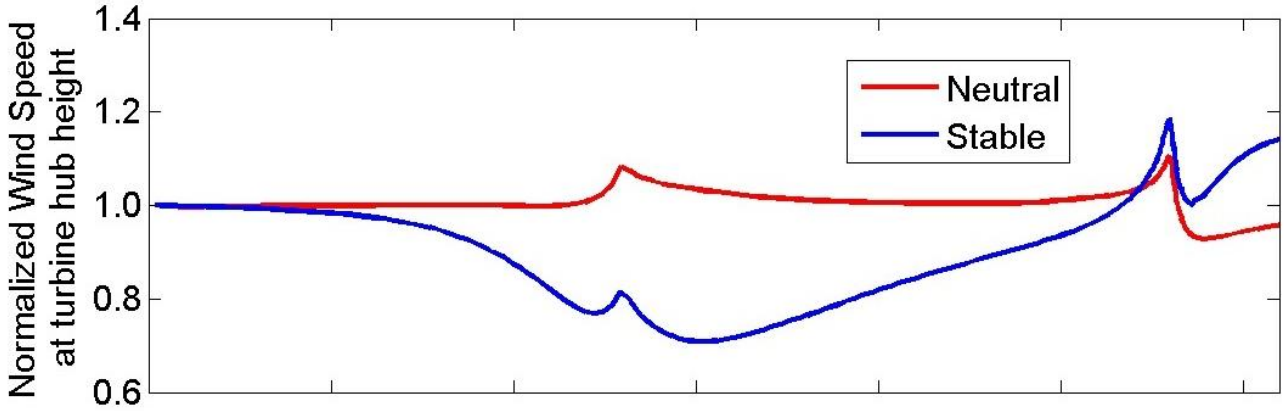
- The flow of air is described by the Navier-Stokes equations
- Difficult to solve given complex mathematics and wide range of scales



Wind flow modelling

- Computational Fluid Dynamics (CFD)





Wind flow modelling

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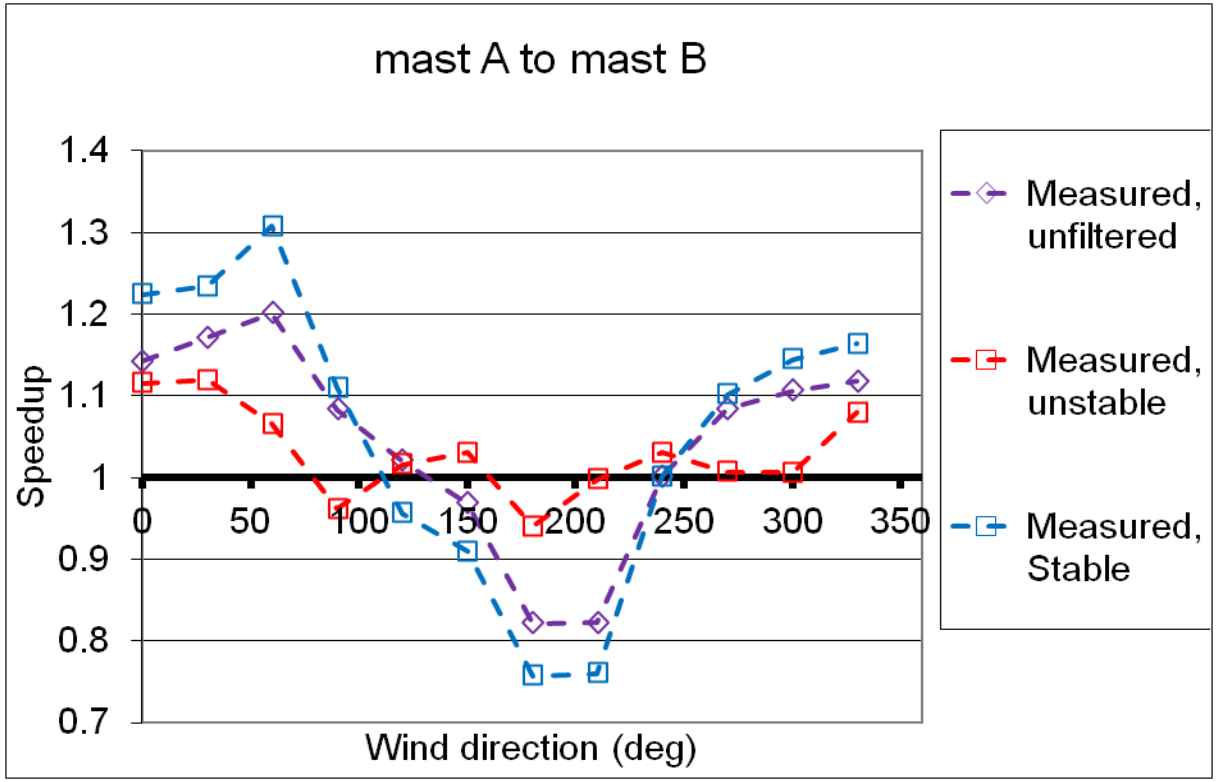


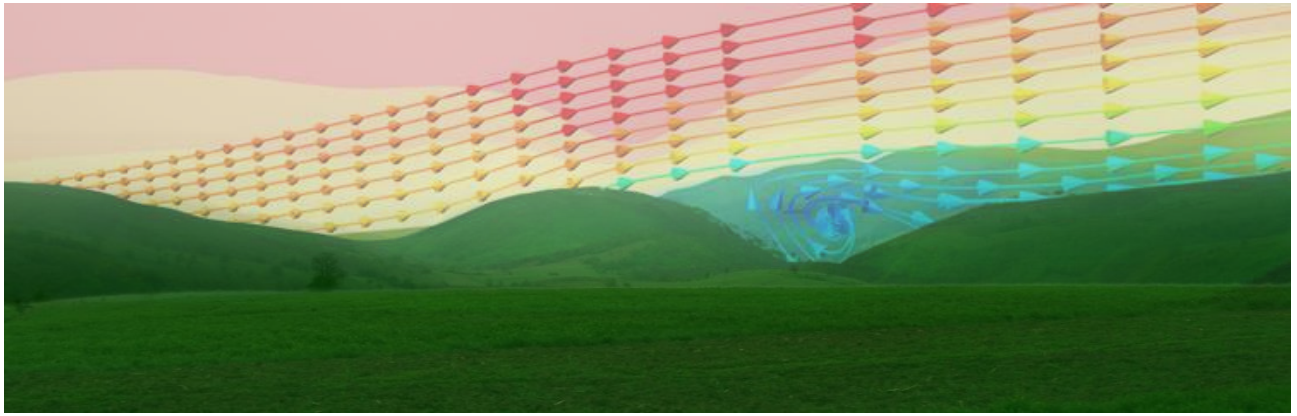
Wind flow modelling

- What can CFD deliver over a linear model?

- More accurate turbine wind speed predictions
- Better wind farm layouts for increased production and reduced risk
- Better assessments of shear, upflow angle, turbulence intensity, flow separation

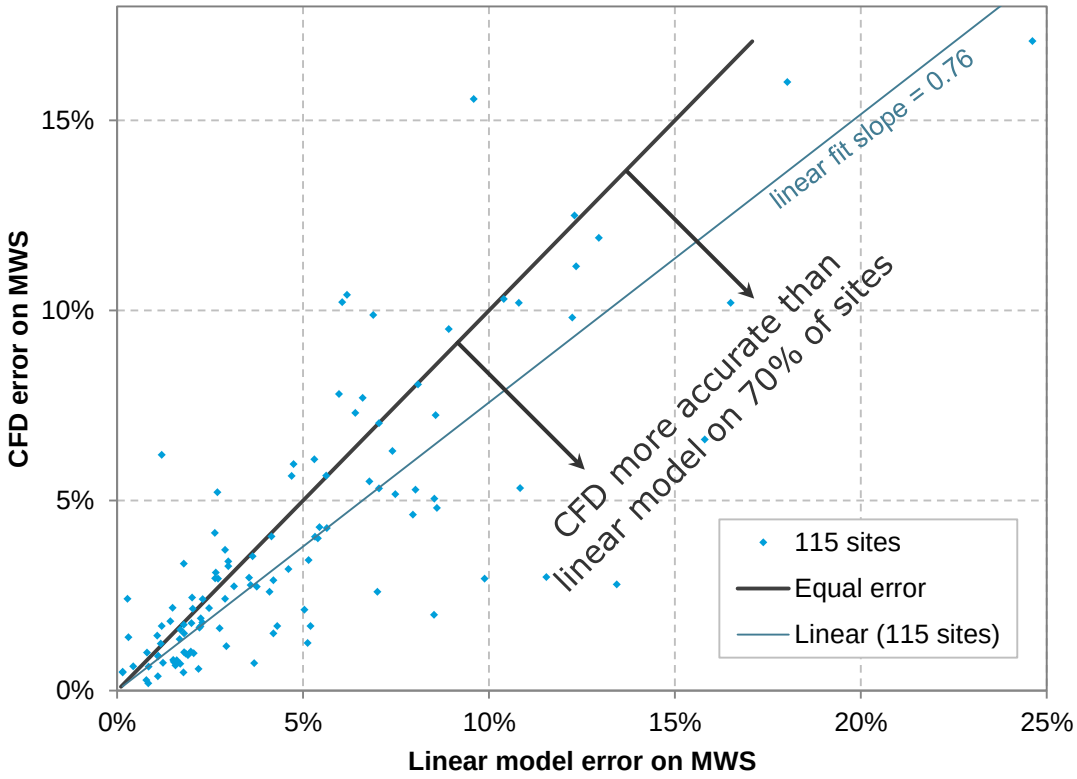
- Reduced uncertainty in Energy Assessments

- Captures the effects of:
  - Complex terrain
  - Atmospheric stability
  - Forestry



Wind flow modelling

- Computational Fluid Dynamics (CFD)
- 115 multi-mast sites analysed with CFD in 2012-2013 (2500 mast pairs)
  - Error on mean wind speed reduced by 20% on average.



Wind flow modelling

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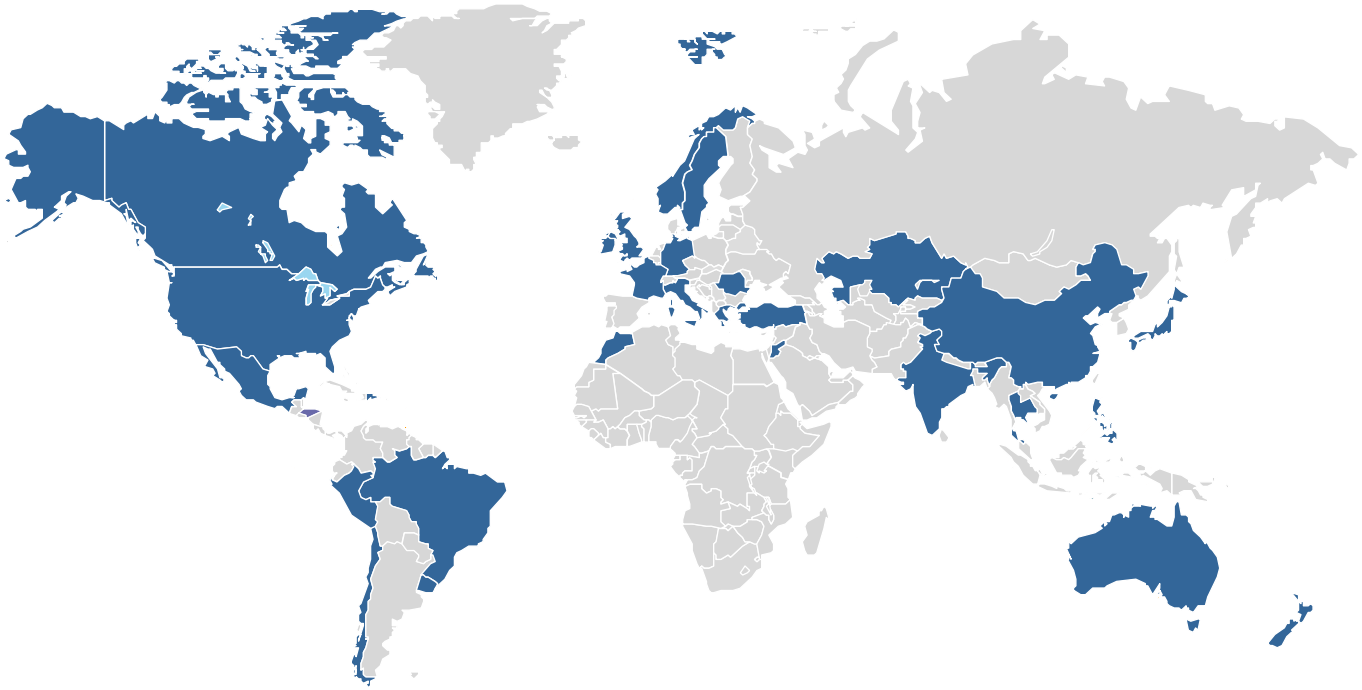
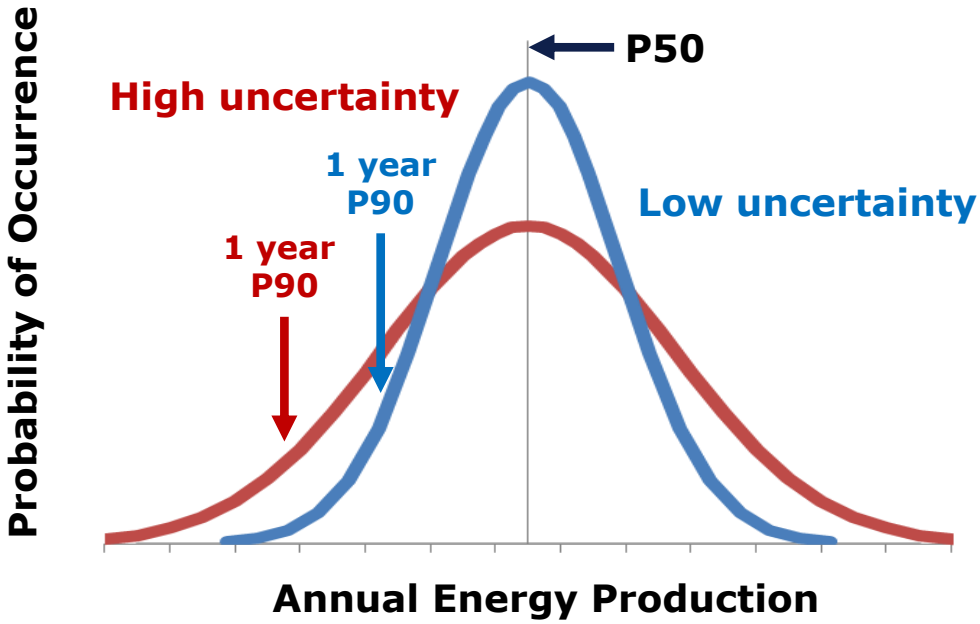
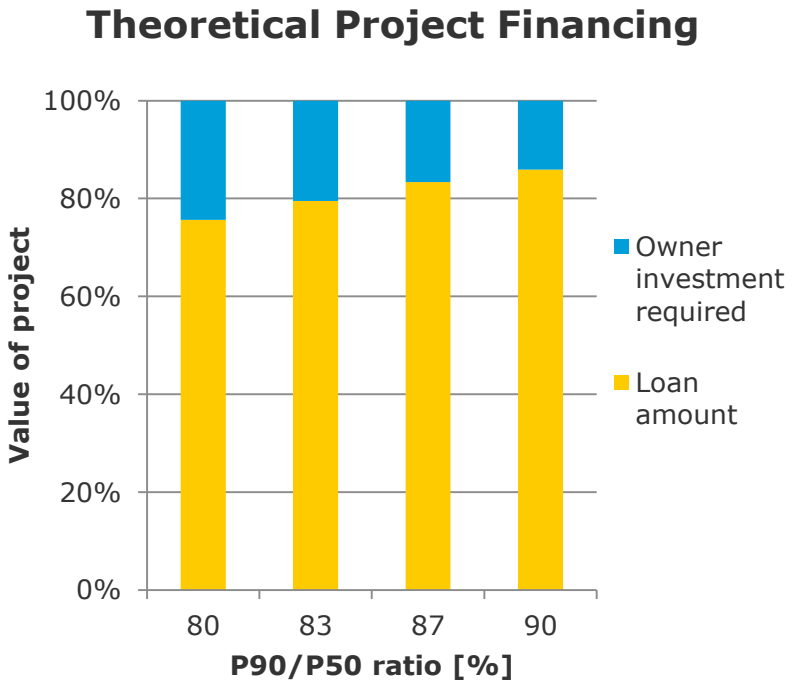
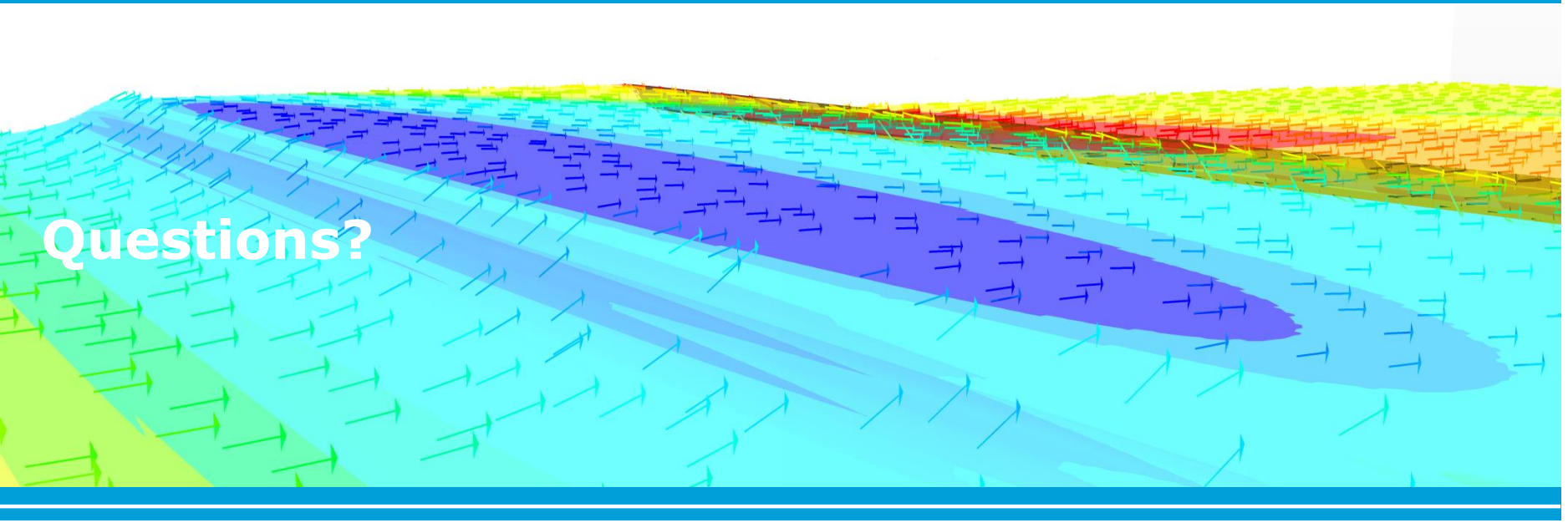


Conclusion

- Discussed here are two new methods for reducing uncertainty in your energy assessments
- What does this mean to the owner of the project?







Questions?

Mark Purcell
m.purcell@dnvgl.com
+61 3 9600 1993

www.dnvgl.com

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