wind energy

solar energy

offshore energy

EWEA Resource Assessment Workshop 2013

Evaluation of four numerical wind flow models

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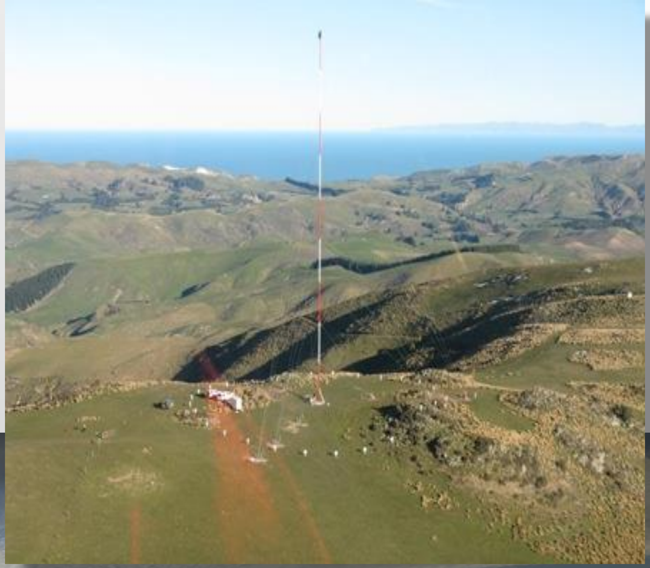
Why Do Wind Flow Modeling?

- Allows extrapolation from a few points to an entire wind farm
- Allows optimization of the plant layout
- Doing it well is essential for accurate energy production estimates



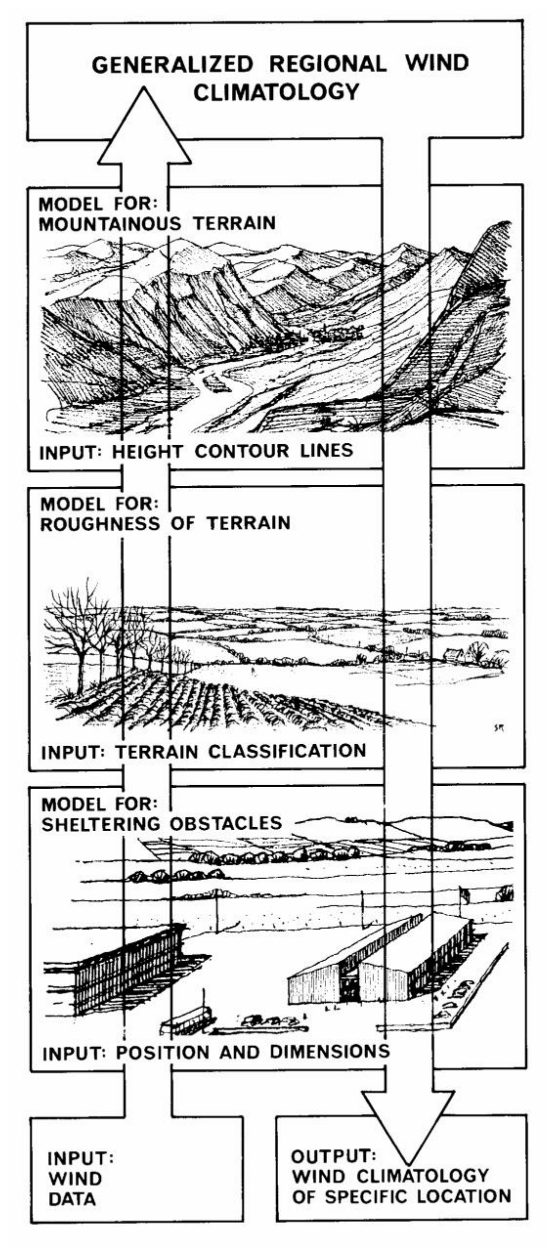
Key Challenges in Wind Flow Modeling

- Spatial resolution must be ~50 m or better over a domain ~25 km or larger
- Must simulate a wide range of wind conditions
- Should simulate all relevant physical processes – but which are relevant?
- More advanced models require much more computer time than simpler models - but are they worth the cost?

Jackson-Hunt*

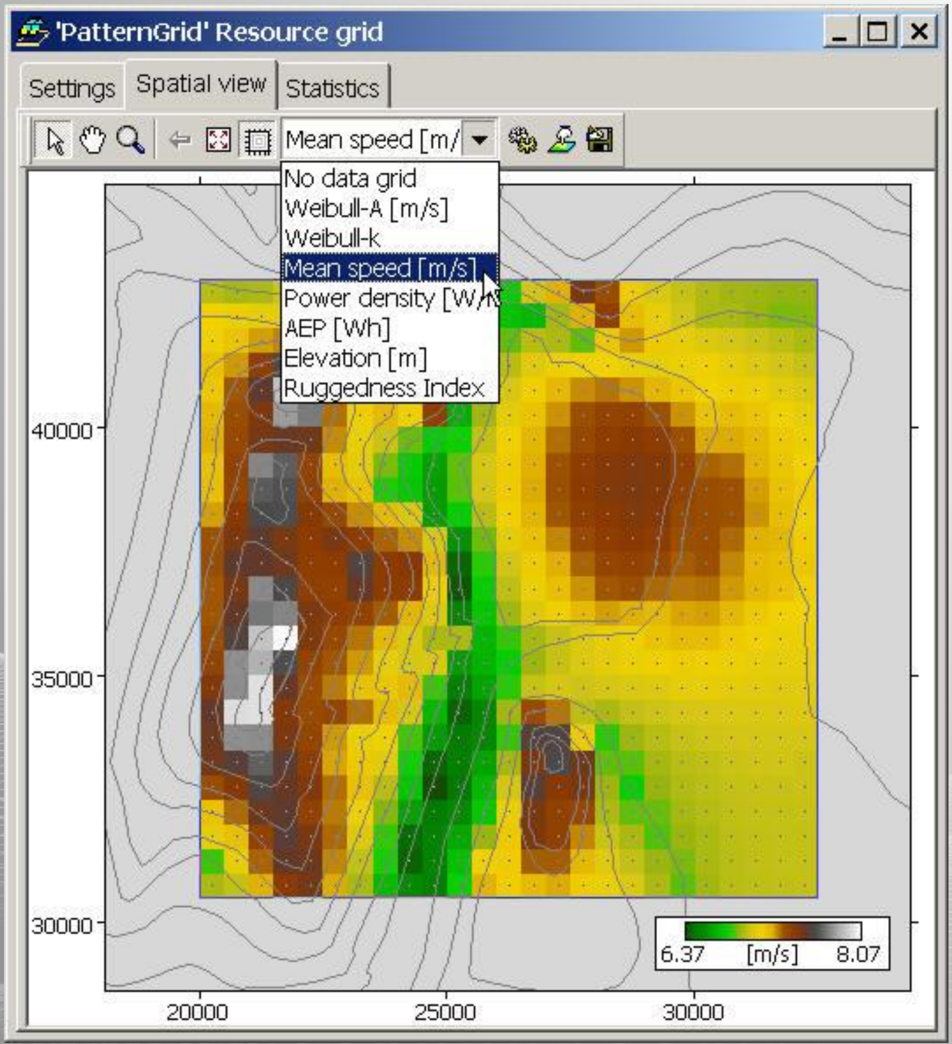
- Fast, linearized, steady-state N-S solver (e.g., WASP)
- Assumes terrain is a small perturbation on a constant background wind field
- Infers the regional wind climate based on point measurements
- Reverses process to extrapolate to other points
- Includes obstacle, surface roughness modules

*Jackson, P.S. and J.C.R. Hunt (1975). "Turbulent Wind Flow over Low Hill". Quart. J. R. Met. Soc., vol. 101, pp. 929-955.



Source: Risoe National Lab

WAsP Example:
Orographic Influence on Wind Speed

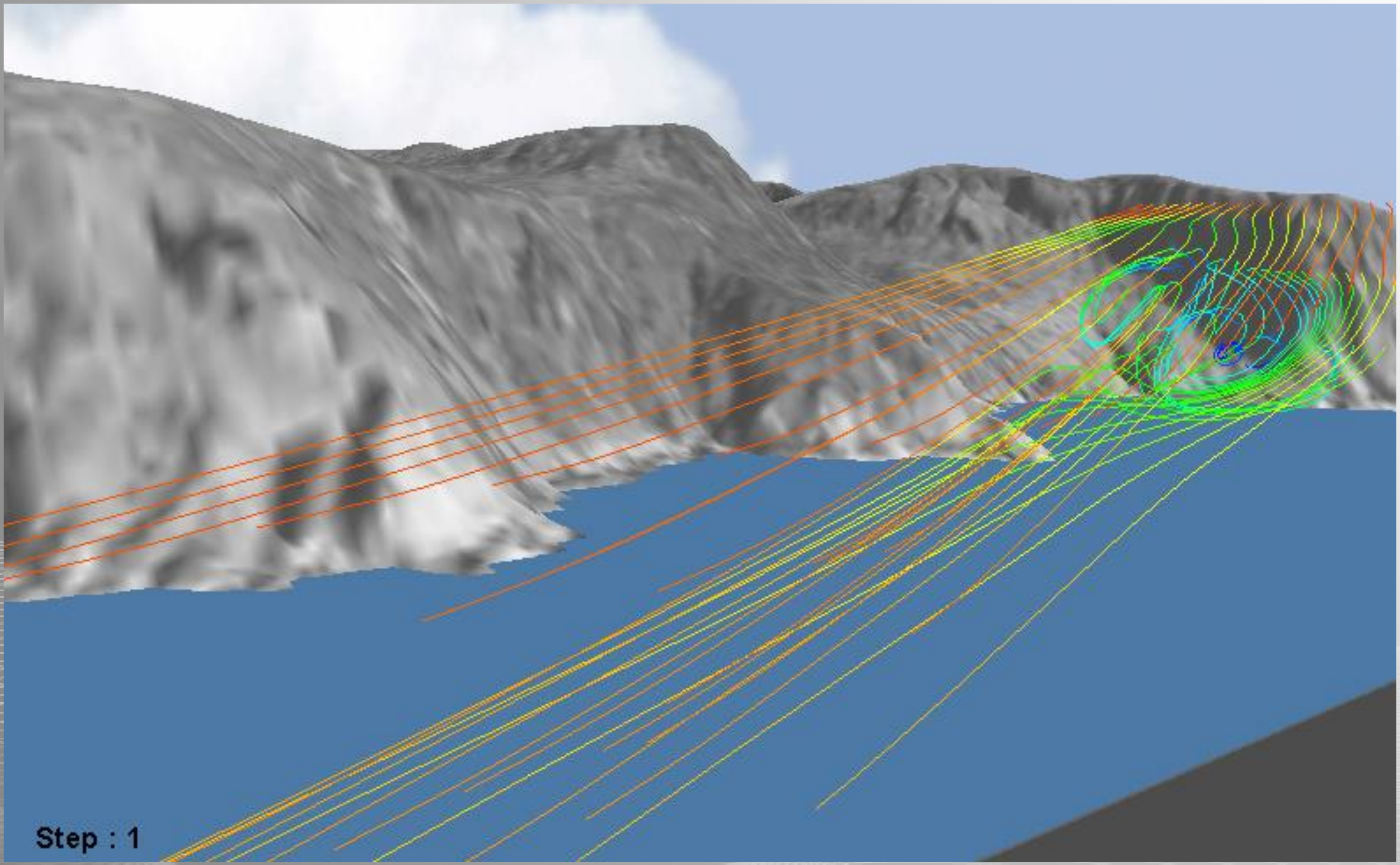


Source: Risoe National Lab

"CFD" Models

- Most are Reynolds-averaged Navier-Stokes (RANS) solvers (e.g., Meteodyn WT, WindSim)
- Divide wind into steady-state and fluctuating (turbulent) components
- Non-linear; can simulate re-circulations, flow separations, other effects of steep terrain
- Usually assume constant, homogeneous boundary conditions, iterate to convergence
- Like JH models, most ignore energy balance, i.e., thermal gradients, thermal stability (buoyancy)

RANS-CFD Example: Recirculation Behind a Ridge

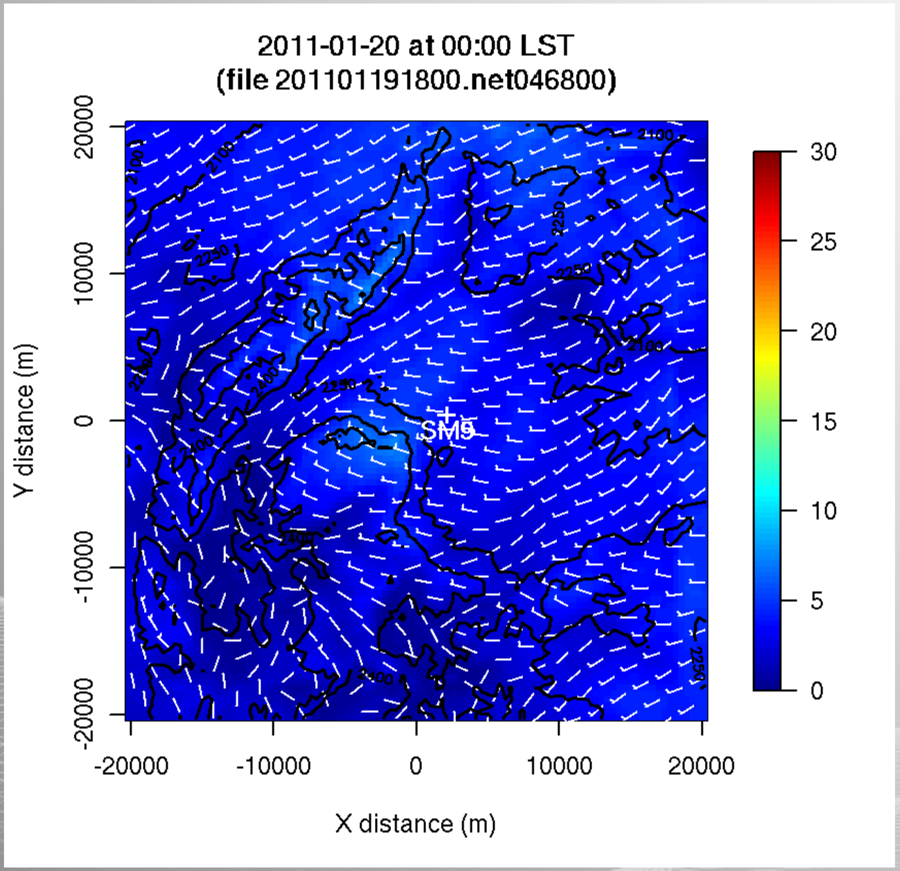


Source: WindSim, Vector AS

Numerical Weather Prediction (NWP) Models

- Full time-varying 3D physical model of the atmosphere. Examples: WRF, MASS, KAMM, ARPS…
- Solve all the primitive equations, including energy balance, surface exchanges, and phase transitions, with turbulence parameterization
- Require 100-1000x as much computer time as linear models; usually done on a high-performance computing cluster
- Can be coupled with linear models to improve resolution, reduce runtime
- Current research: Coupled large eddy simulations to resolve the larger scales of turbulence

NWP Example: Gravity Wave



Research Outline

- Objectives:
  - Determine whether accuracy improves with more advanced models
  - Examine factors influencing accuracy
- Round-robin approach:
  - Use one mast to predict the mean wind speed at the other masts
  - Calculate errors (predicted minus observed mean speed)
  - Repeat with other masts
  - 144 independent mast pairs provide a robust statistical sample
- Compile root-mean-square error (RMSE) for all models & cases
- Test dependence on distance, elevation difference, etc.

Sampling of Prior Research

Authors	Models Compared	No. Sites	Mast Pairs	Distance Scale (km)	Conclusion
Cabezon et al. 2006 (CENER)	WAsP, RANS-CFD	1	2	4	RANS-CFD 70% smaller error
Berge et al. 2007 (Kjeller Vindteknik)	WAsP, RANS-CFD	1	2	1-2	WAsP 0-40% smaller error
Bolund: Bechmann et al. 2011 (Risoe)	Multiple Linear, RANS-CFD, LES	1	8	~0.1-0.2	RANS-CFD ~30-40% smaller error
Corbett et al. 2012 (GL/GH)	Linear, RANS-CFD	13	74	N/A	RANS-CFD ~25% smaller error

Models

- Jackson-Hunt: WASP (Risoe)
- RANS CFD: Meteodyn WT (Meteodyn)
- NWP-Mass Consistent: SiteWind (AWS Truepower)
- NWP-LES: ARPS (AWS Truepower)

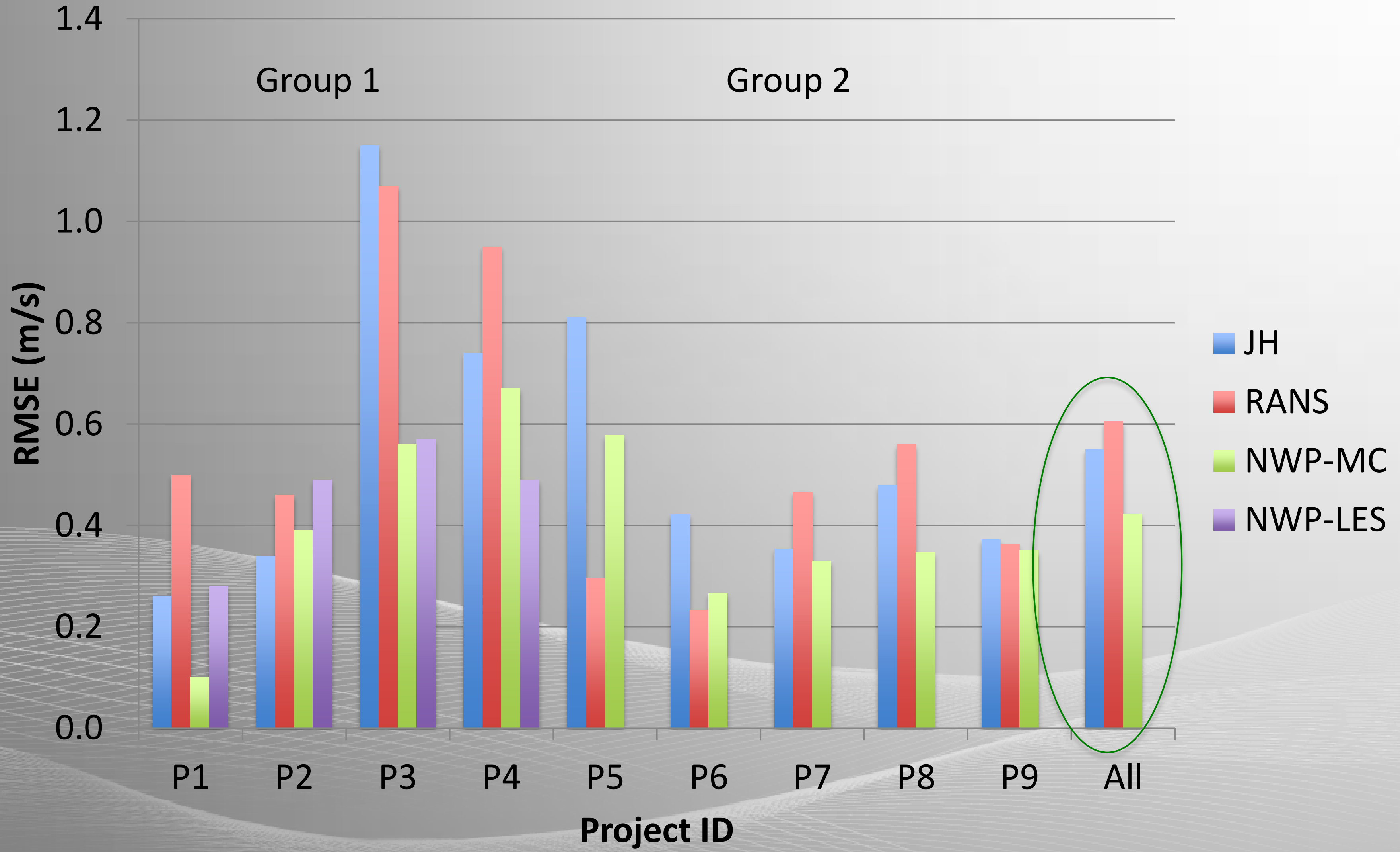
Projects

- Group 1: Four US projects initially studied in 2011 (Beaucage et al. *Wind Energy*, 2012)
  - 25 masts, 74 independent mast pairs
- Group 2: Five additional US and Spanish projects
  - 28 masts, 70 independent mast pairs
- Meta-analysis of combined groups yields greater statistical reliability: 9 sites, 53 masts, 144 mast pairs

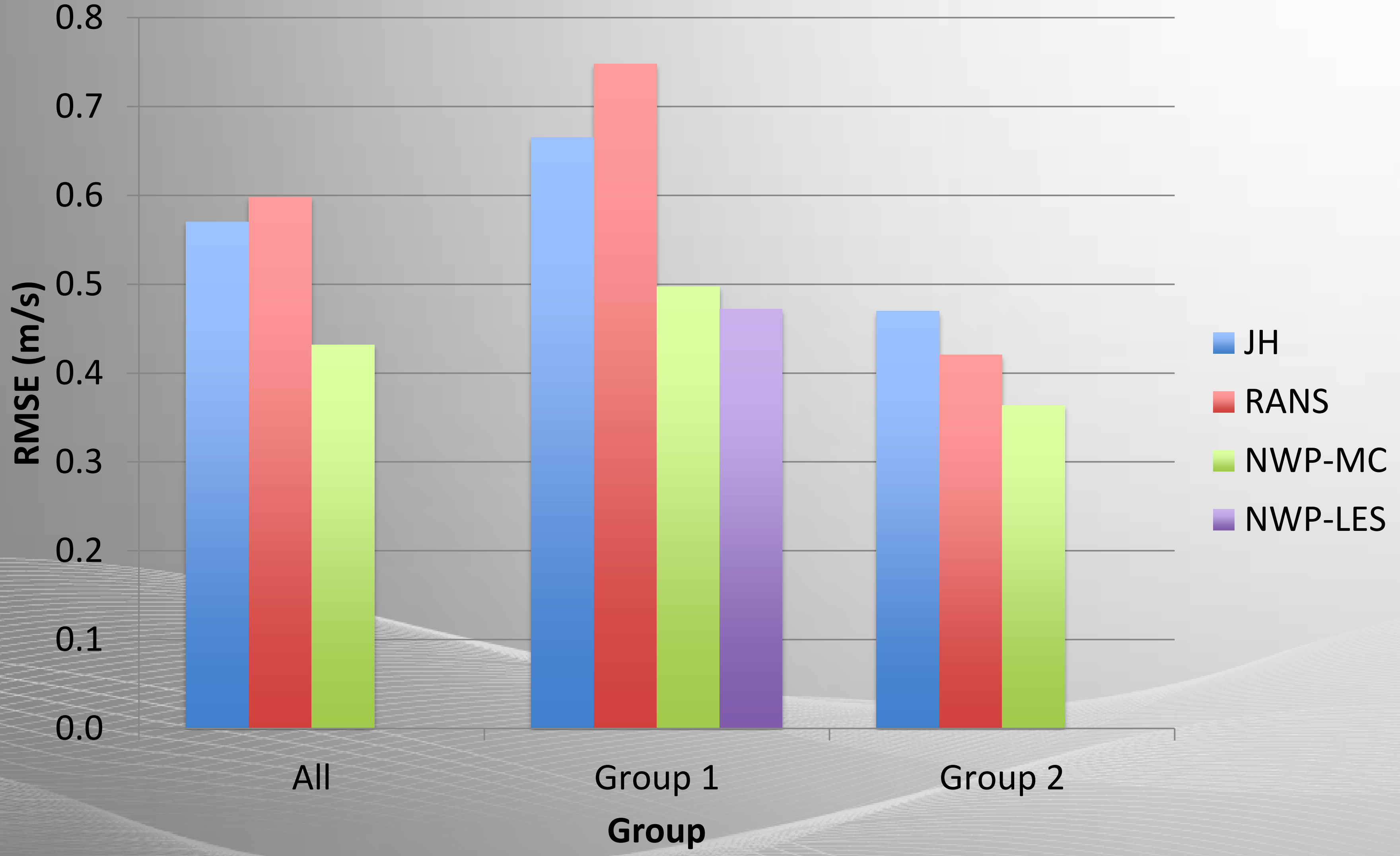
Case Projects

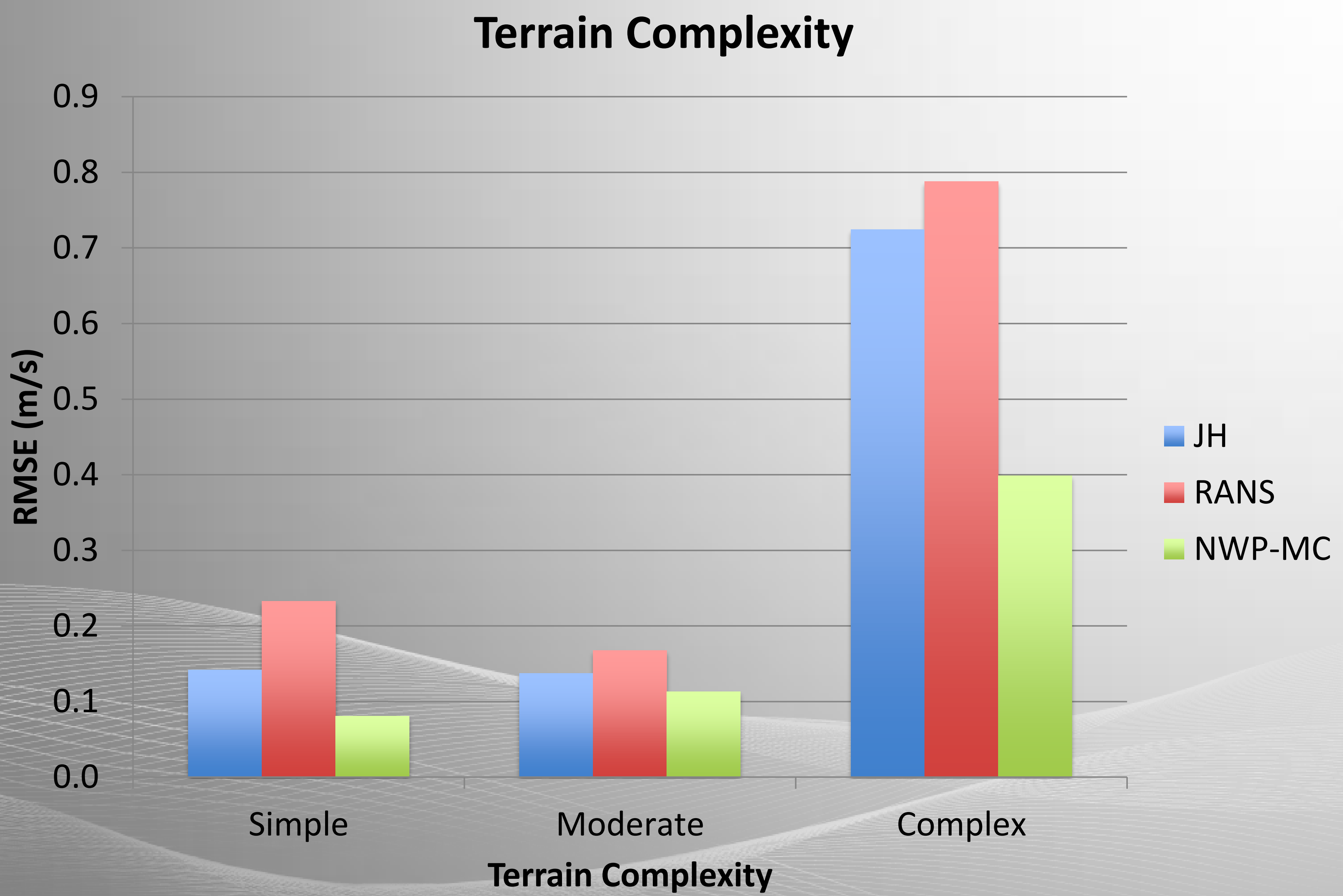
Project	Group	Terrain	Land Cover	No. Masts
1	1	Simple	Grass, some trees	8
2	1	Moderate	Grass, shrubs	6
3	1	Complex coastal	Mostly forest	3
4	1	Complex	Forest	8
5	2	Complex	Grass, shrubs	3
6	2	Moderate	Grass, trees	5
7	2	Moderate	Grass, trees	6
8	2	Simple	Grass	7
9	2	Simple	Grass, shrubs	7

RMSE by Project

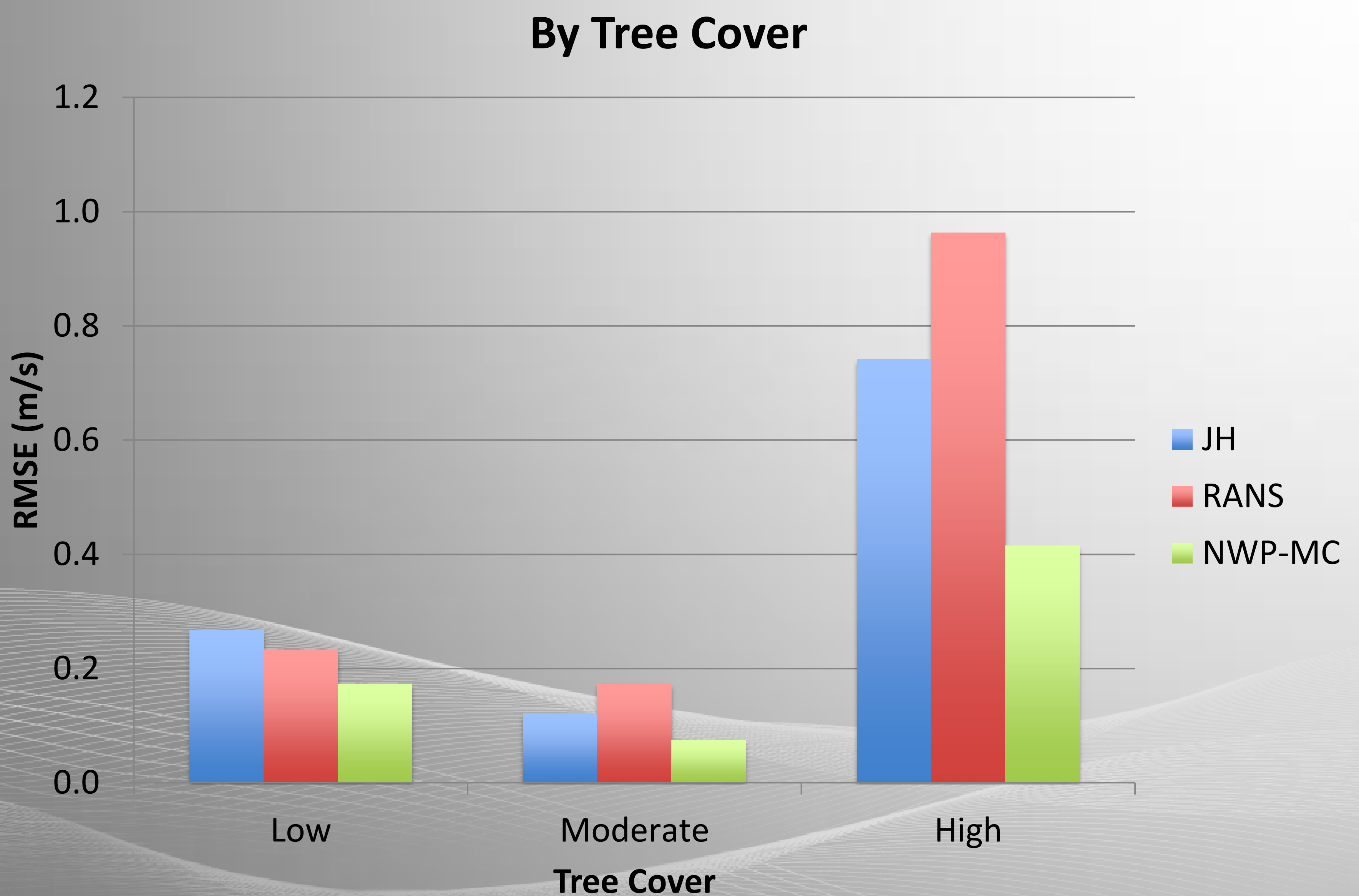


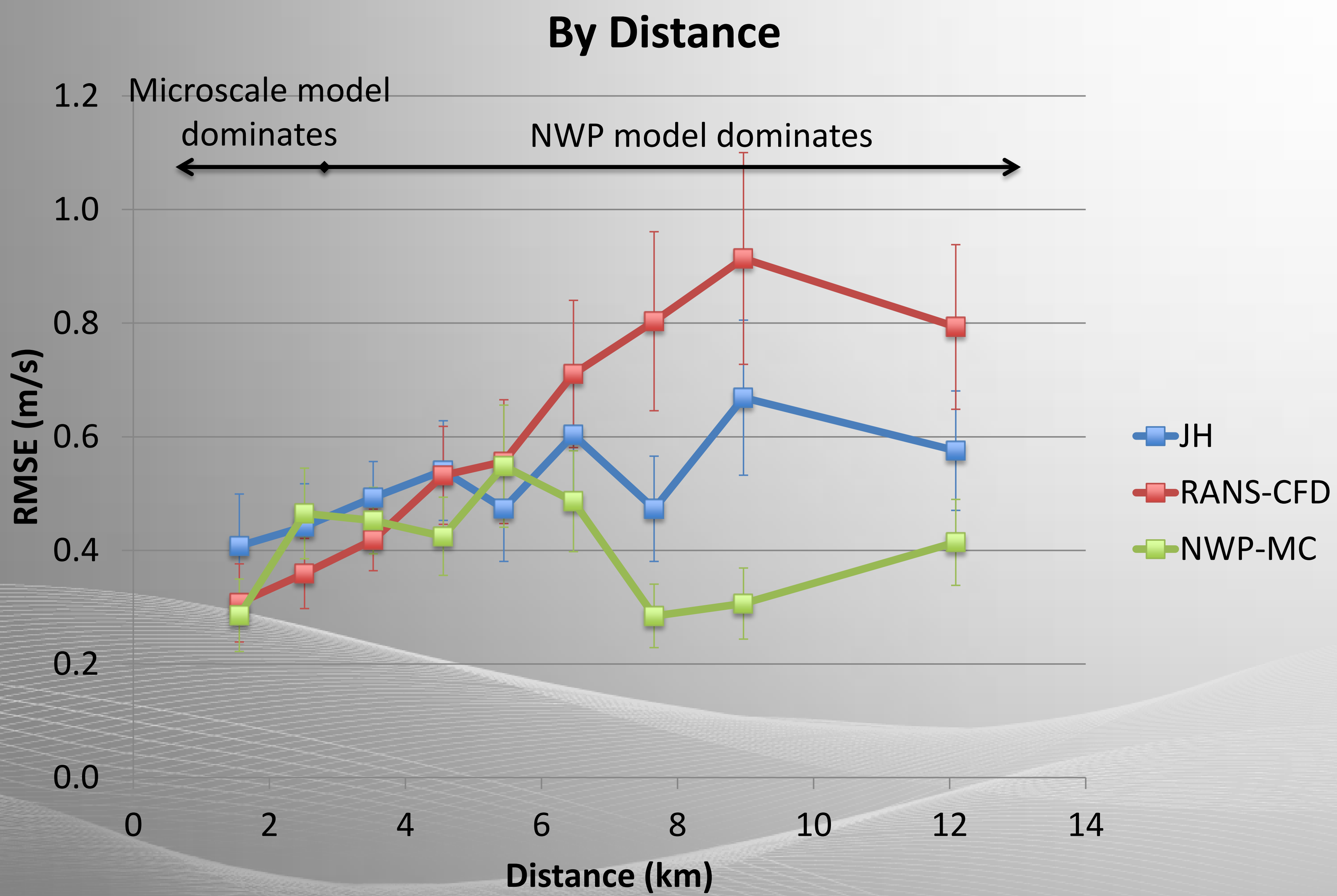
By Group


0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
RMSE (m/s)
All
Group 1
Group 2
Group
JH
RANS
NWP-MC
NWP-LES



Terrain Complexity
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
RMSE (m/s)
Simple
Moderate
Complex
Terrain Complexity
JH
RANS
NWP-MC


By Tree Cover
1.2
1.0
0.8
0.6
0.4
0.2
0.0
RMSE (m/s)
Low
Moderate
High
Tree Cover
JH
RANS
NWP-MC


By Distance
Microscale model dominates
NWP model dominates
RMSE (m/s)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
2
4
6
8
10
12
14
Distance (km)
JH
RANS-CFD
NWP-MC

Conclusions

- Absolute and relative performance vary greatly from site to site
- For this sample of projects
  - Complex, forested terrain produce a large (4-5 x) increase in errors for all models
  - At short distance scales, all three models perform about the same; RANS CFD may have a small edge
  - As distances increase, NWP-based models perform better, suggesting importance of thermal gradients
  - NWP-LES models show promise
- Meta-analyses of multiple sites should be pursued, as they yield insights not available to detailed experiments at single sites