I WORKSHOP BRASILEIRO SOBRE MODELAGEM DA ATMOSFERA
APLICAÇÕES NA ÁREA DE ENERGIA EÓLICA

CTGAS-ER | NATAL-RN
14 e 15 junho de 2018

Desafios e Limitações da Modelagem Numérica na Avaliação dos Recursos Eólicos: A importância da parametrização da rugosidade, topografia e estabilidade na modelagem em microescala.

CAMARGO SCHUBERT

DSc. Ramon Morais de Freitas
Camargo-Schubert
Pesquisador Associado - Sensoriamento Remoto

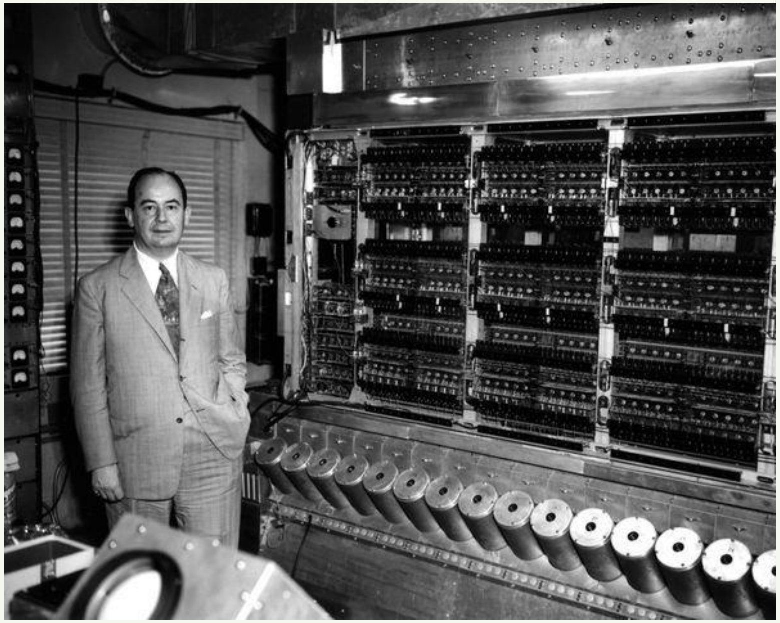
CTGAS-ER Centro de Tecnologias do Gás & Energias Renováveis

FIERN SESI SENAI IEL SENAI Serviço Nacional de Aprendizagem Industrial - DR/RN

CAMARGO SCHUBERT

Evolução da modelagem numérica em ciências atmosféricas

2018



John von Neumann with the IAS Computer - Princeton, 1951
Courtesy of the Shelby White and Leon Levy Archives Center, Institute for Advanced Study (IAS)

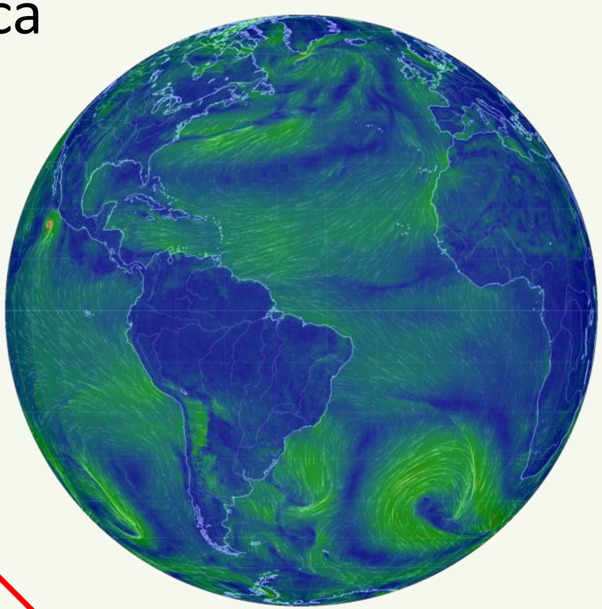
Edward Norton Lorenz

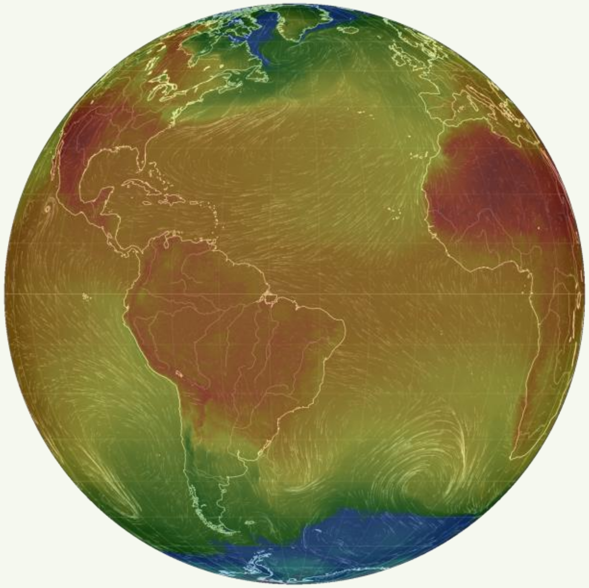
Predictability: Does the Flap of a Butterfly's Wings in Brazil set off a Tornado in Texas? - Edward Lorentz, AAAS, (1972)

Sistemas Complexos

Trilhões de horas de pesquisa

- -Matemática
- -Física
- -Meteorologia
- -Engenharia
- -Computação
- -Observação da Terra





https://earth.nullschool.net

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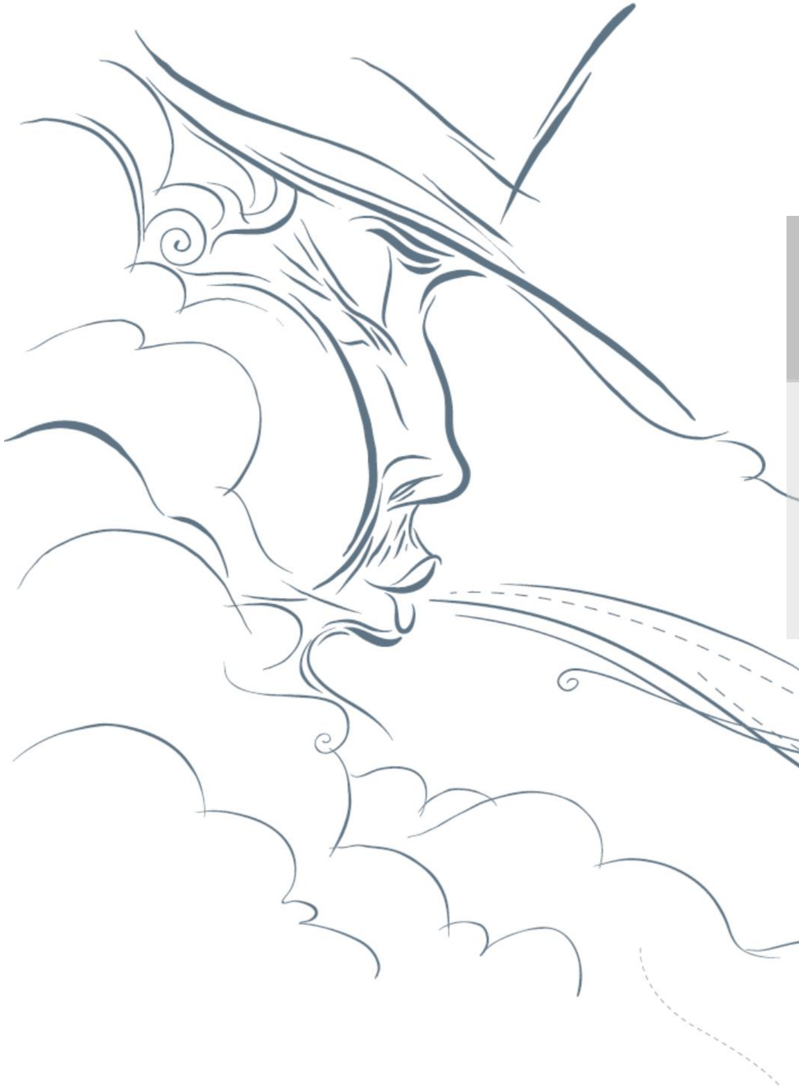


Roteiro:

- A Camargo-Schubert
- Escalas na Modelagem da Atmosfera
- Desafios e Limitações (literatura técnico-científica)
- Exemplos de Parametrização em Microescala
  - Estabilidade
  - Rugosidade Aerodinâmica
  - Resolução espacial em relevos complexos
- Considerações Finais

Parte 1 – Desafios e Limitações

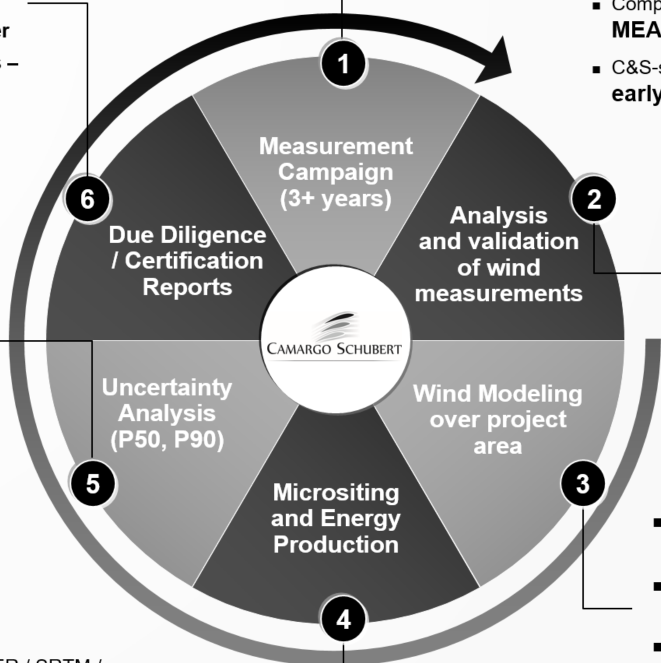
Parte 2 –Exemplo simplificado de um problema de engenharia

Certification of Projects

CAMARGO SCHUBERT has introduced differentiated procedures for development and certification of wind projects…

- **Experience** with more than 800 wind measurement towers
- **Quality System based on aeronautical industry standards**: focus on reducing uncertainties
- Compliance with international standards**: IEC 61400-12-1 and MEASNET**
- C&S-software, **Wind Sentinel© for daily monitoring and early warning** of non-conformities to increase recovery rate

- Identification of potential risks or upside (in case of due diligence)
- **Certification for financing – BNDES, Santander**
- **Certification for International Rating Agencies – FItchRatings, Moody's, S&P**



- **Mesoscale-based interpolation** of all measured wind data **to reduce distance-to-tower uncertainties**
- Vertical extrapolations**: thermal stability effects considered to reduce uncertainty**
- **Long-term energy yield** estimates based on thorough analysis of all existing long-term wind references, **observing conservative criteria within calculated uncertainties**

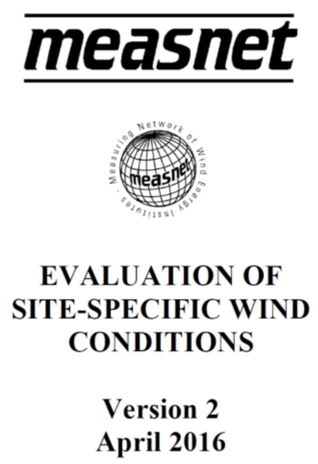
- **Cross-checking with nearest measured data** validated by C&S
- Iterative **determination of atmospheric thermal stability** parameters: diurnal and seasonal patterns
- Long term energy yield data series (20 years): **empirical adjustment of reanalysis data to mesoscale** effects

- **Mesoscale** data runs provided by **AWS Truepower, Microscale** run by **CAMARGO-SCHUBERT**
- **Katabatic winds and thermal stability effects** modelled and adjusted by wind data
- **Wind resource file** (for micrositing and energy production estimates) **matches all measured data**
- Extensive ongoing **investigation** of wind and thermal stability effects in complex terrain in Northeast Brazil, using **3 programmable laser-scanning LIDARs in conjunction with 120m and 100m towers**

- **High resolution grid terrain** models (ASTER / SRTM / laserscan)
- **Roughness: remote sensing techniques** to improve accuracy of roughness maps
- **AeroPARK**© has added the **ability to model Weibull bimod**al distributions**, diurnal and seasonal contrasting wind regimes**

…aiming at reducing its risk profile and improving bankability

Atividades do Processo de Certificação



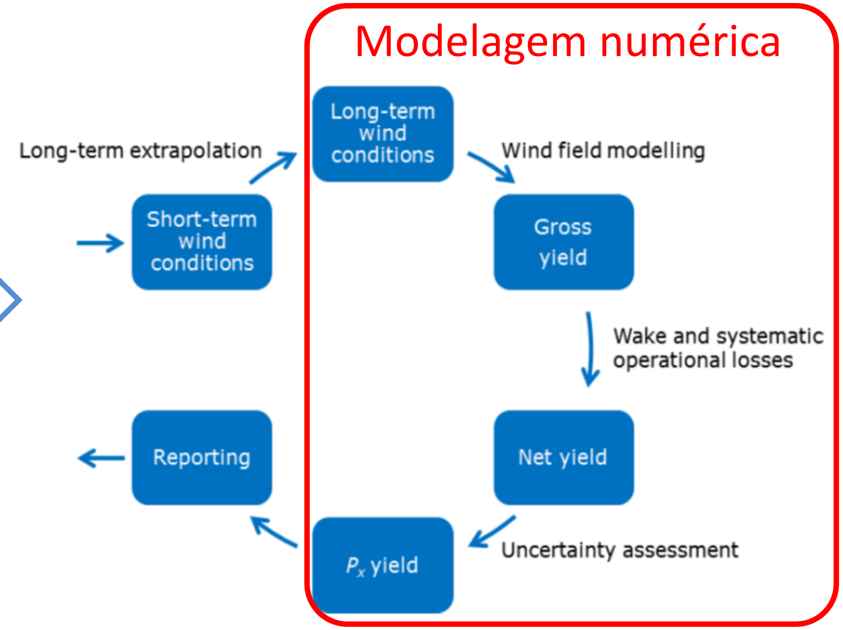
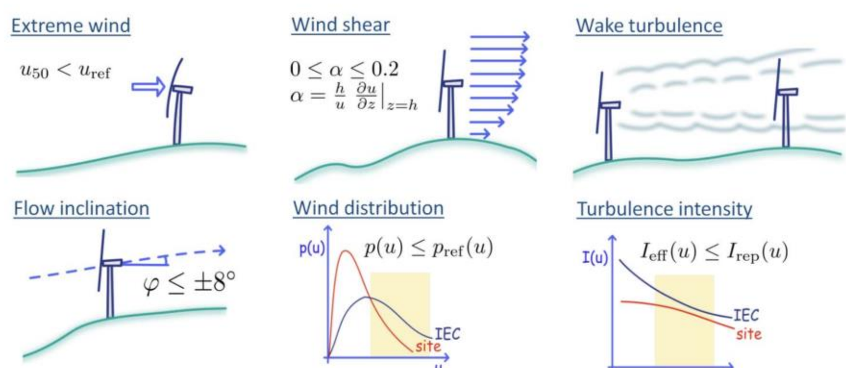


Figure 6: Main steps in the Energy Yield Assessment process.

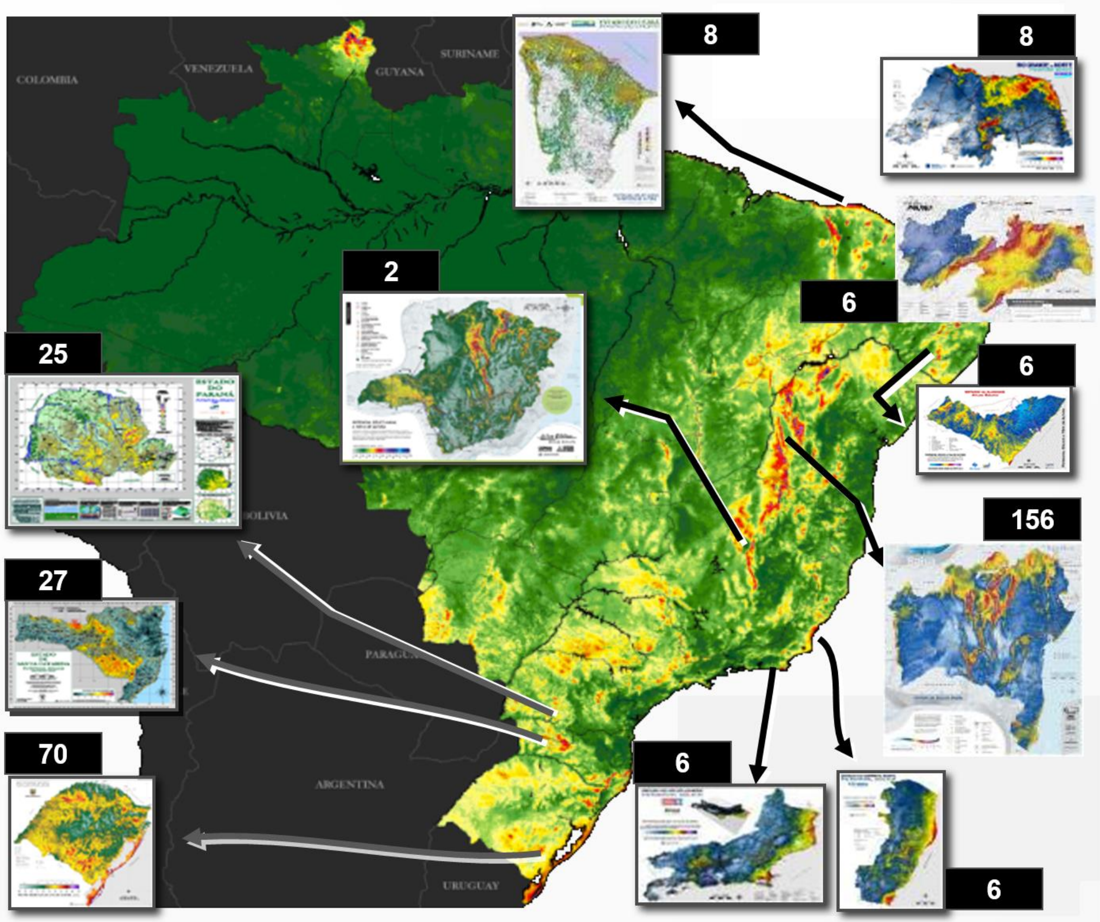


Source. http://www.wasp.dk/wat#iec-61400-1

CAMARGO SCHUBERT

18 years detailing the Brazilian wind energy resource

The most complete wind database, with over 18 years of measurement, data analysis and mesoscale wind mapping



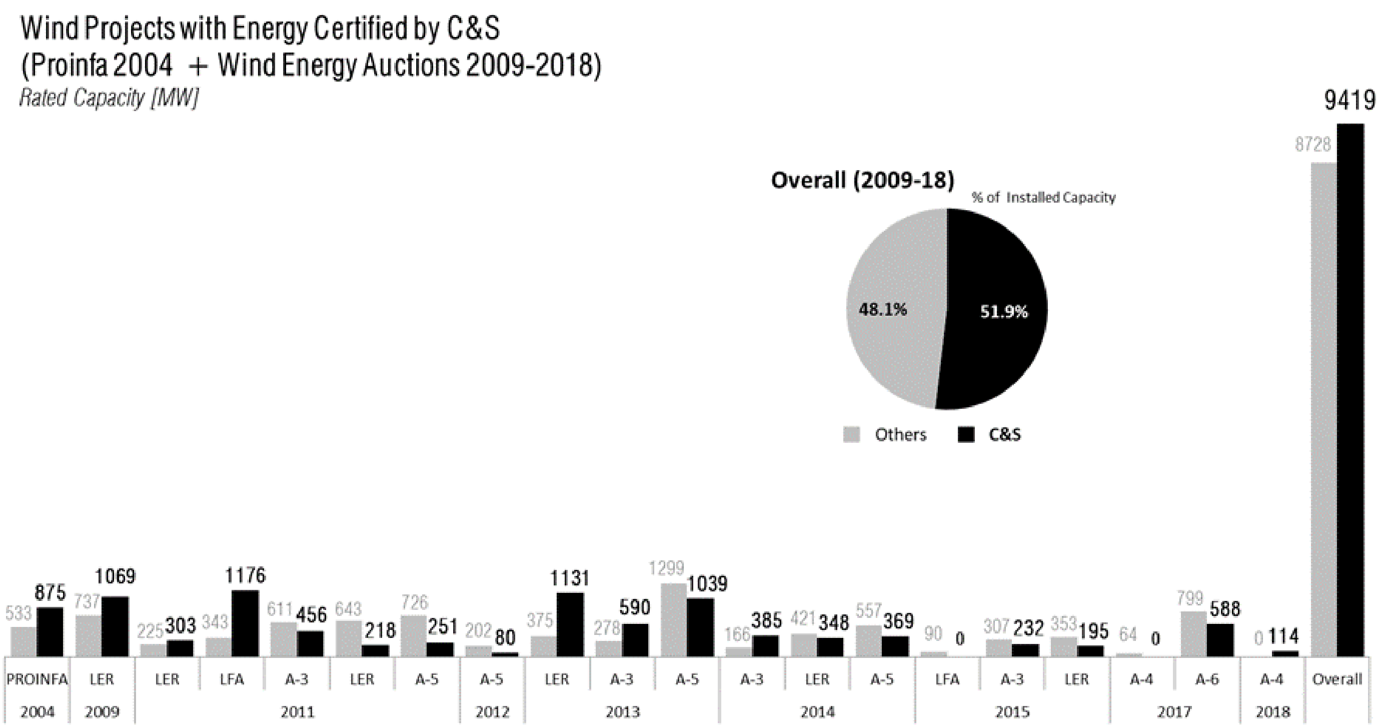
Year	State	
2017	Paraíba	
2014	Rio Grande do Sul	
2013	Bahia	Bahia Governo
2010	Minas Gerais	CEMIG A Melhor Energia do Brasil
2009	Espírito Santo	edp escelsa
2008	Alagoas	Eletrobras
2007	Paraná	COPEL
2003	Rio de Janeiro	Governo do Estado RJ
2003	R. Grande do Norte	IBERDROLA
2002	R. Grande do Sul	
2002	The Brazilian Wind Atlas	Eletrobras
2001	Bahia	IBERDROLA
2000	Santa Catarina	Celesc
1999	Ceará	endesa

# of Wind Masts

Responsible for the preparation of the Brazilian Wind Resources Atlas, among others

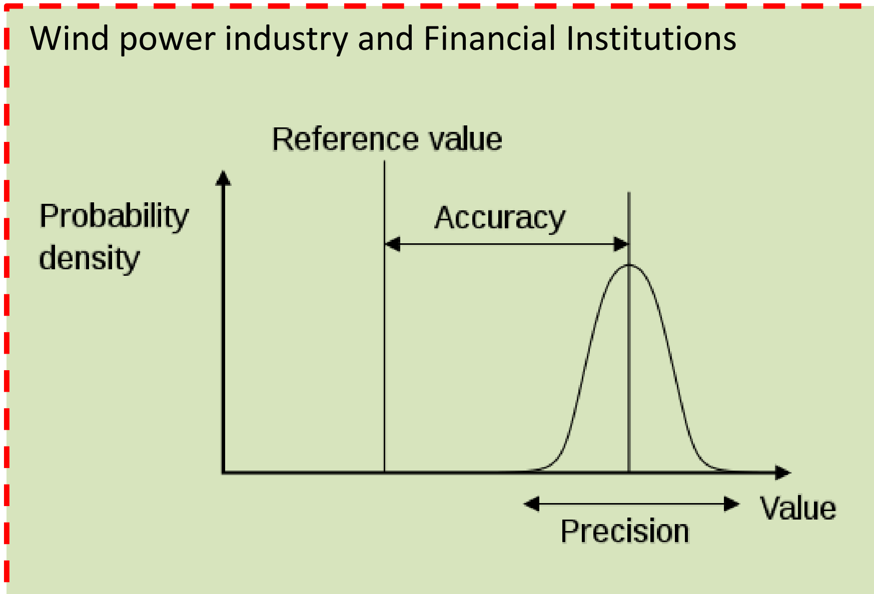
Experiência na Certificação de Parques Eólicos

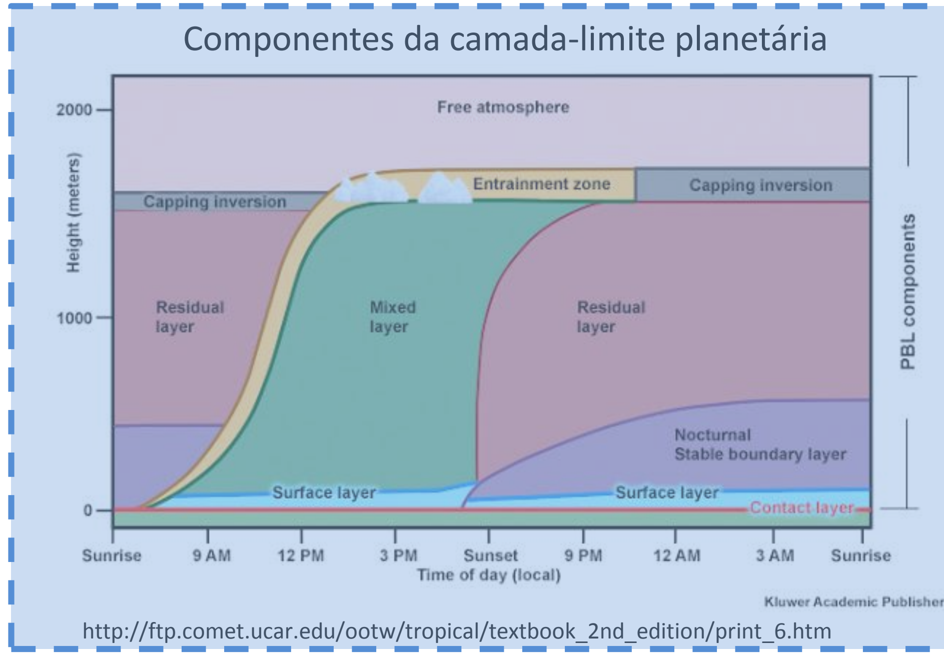
- 9.4 GW ou 51.9% dos projetos com energia comercializada no ACR (até 2018)
- Plenamente aceita pelo BNDEs e EPE
- Responsável pela certificação de mais 10 GW em projetos em desenvolvimento



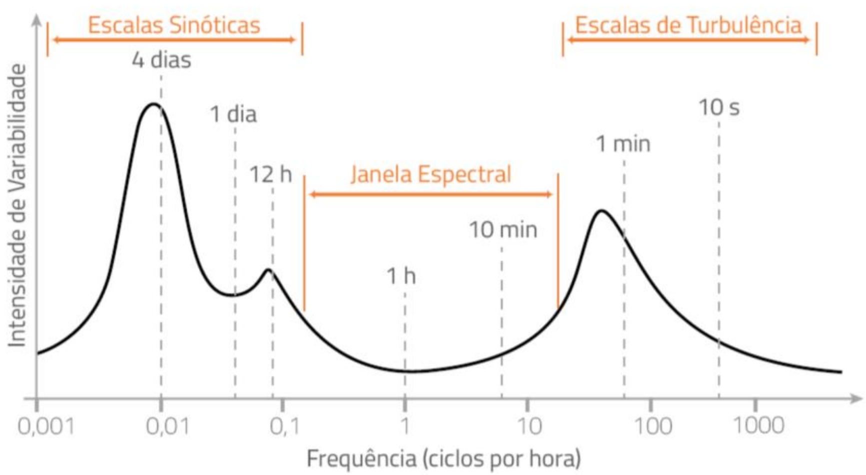
Principais Clientes

O que queremos com a modelagem atmosférica?





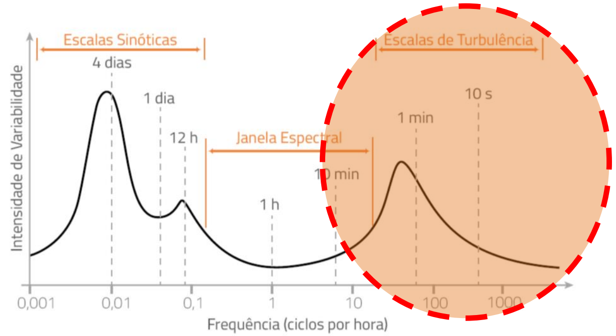
- Precisamos entender e modelar a variabilidade do vento

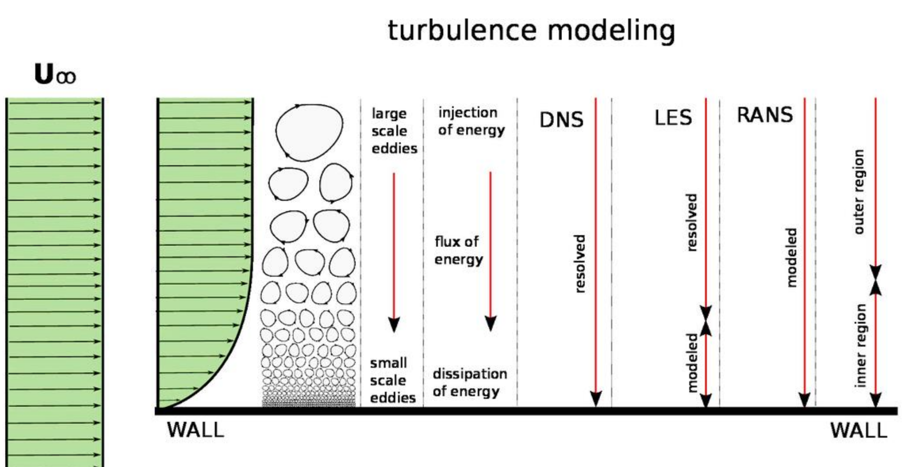


Meteorologistas
Engenheiros
Pesquisadores

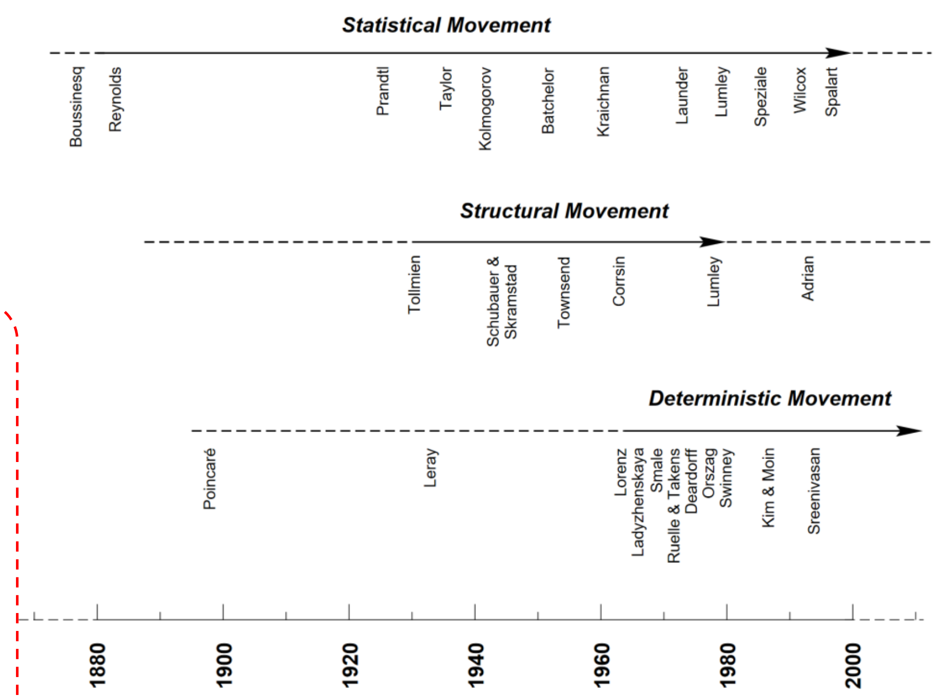
A Importância da pesquisa básica para ciências aplicadas e engenharia

- A previsibilidade passa por entender e modelar os processos turbulentos





Fonte: Adaptado https://www.cfdsupport.com/OpenFOAM-Training-by-CFD-Support/node287.html



Fonte: J. M. McDonough. INTRODUCTORY LECTURES on TURBULENCE Physics, Mathematics and Modeling
http://web.engr.uky.edu/~acfd/lctr-notes634.pdf

Taxionomia das Escalas na Modelagem Numérica – Indústria Eólica

Advanced Review

Mesoscale to microscale wind farm flow modeling and evaluation

Javier Sanz Rodrigo,[1*] Roberto Aurelio Chávez Arroyo,[1] Patrick Moriarty,[2] Matthew Churchfield,[2] Branko Kosović,[3] Pierre-Elouan Réthoré,[4] Kurt Schaldemose Hansen,[5] Andrea Hahmann,[4] Jeffrey D. Mirocha[6] and Daran Rife[7]

The increasing size of wind turbines, with rotors already spanning more than 150 m diameter and hub heights above 100 m, requires proper modeling of the atmospheric boundary layer (ABL) from the surface to the free atmosphere. Furthermore, large wind farm arrays create their own boundary layer structure with unique physics. This poses significant challenges to traditional wind engineering models that rely on surface-layer theories and engineering wind farm models to simulate the flow in and around wind farms. However, adopting an ABL approach offers the opportunity to better integrate wind farm design tools and meteorological models. The challenge is how to build the bridge between atmospheric and wind engineering model communities and how to establish a comprehensive evaluation process that identifies relevant physical phenomena for wind energy applications with modeling and experimental requirements. A framework for model verification, validation, and uncertainty quantification is established to guide this process by a systematic evaluation of the modeling system at increasing levels of complexity. In terms of atmospheric physics, 'building the bridge' means developing models for the so-called 'terra incognita,' a term used to designate the turbulent scales that transition from mesoscale to microscale. This range of scales within atmospheric research deals with the transition from parameterized to resolved turbulence and the improvement of surface boundary-layer parameterizations. The coupling of meteorological and wind engineering flow models and the definition of a formal model evaluation methodology, is a strong area of research for the next generation of wind conditions assessment and wind farm and wind turbine design tools. Some fundamental challenges are identified in order to guide future research in this area. © 2016 John Wiley & Sons, Ltd

How to cite this article:
WIREs Energy Environ 2016. doi: 10.1002/wene.214

INTRODUCTION

The renewable energy roadmap of the International Renewable Energy Agency[1] shows a 2030 scenario with 36% share of renewable energy in the global energy consumption by 2030, doubling the renewable energy use with respect to 2010. This would cap CO_2 emissions below the widely accepted climate change tipping point of 2°C increase in global temperature above preindustrial levels by 2100.This scenario envisions wind energy as the fastest growing renewable energy technology to increase the share of global energy demand from 2% in 2010 to 11% in 2030.

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Conflict of interest: The authors have declared no conflicts of interest for this article.

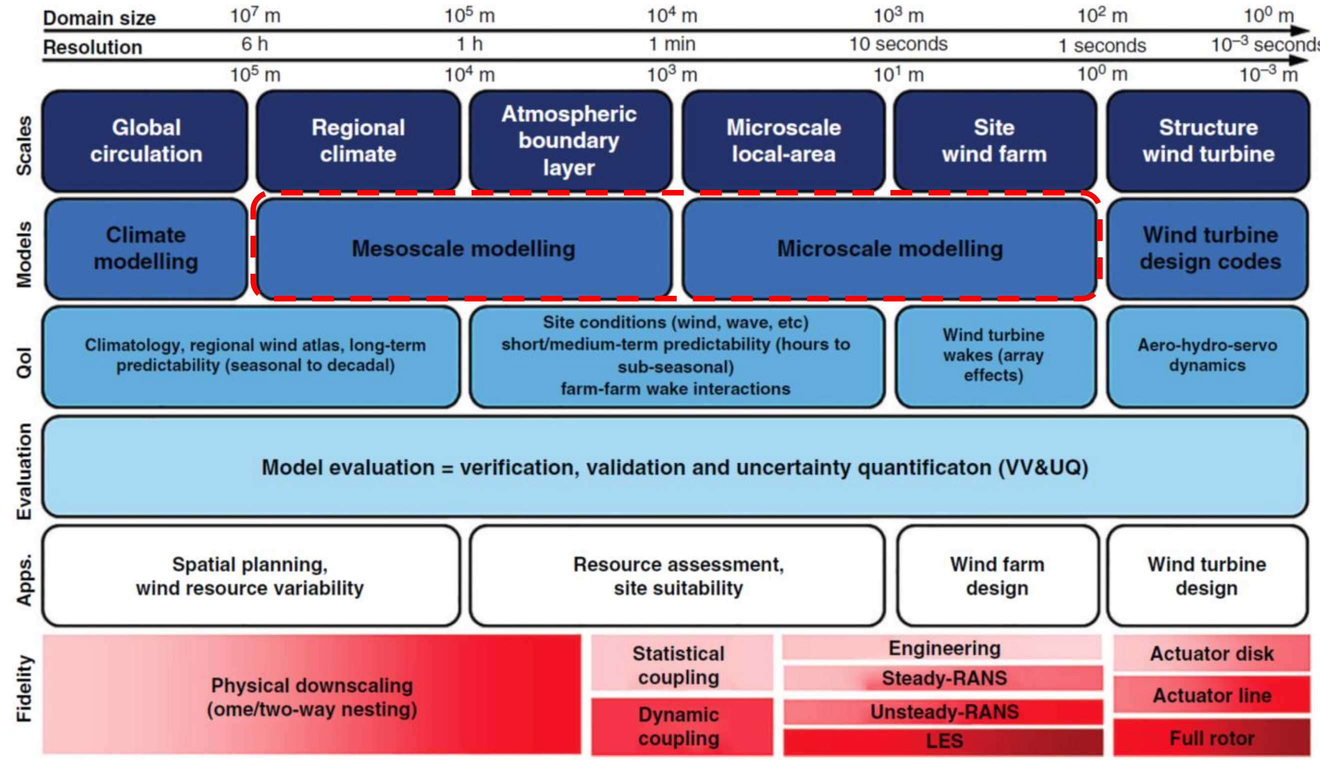

FIGURE 2 | Wind assessment modeling framework indicating typical model scale ranges, relevant outputs for different applications, and high-level fidelity levels (the shading indicates the computational cost). All the models share a common model evaluation framework although each model category has different quantities of interest (QoI) and performance metrics depending on the intended use (application).

Sanz Rodrigo, J. , Chávez Arroyo, R. A., Moriarty, P. , Churchfield, M. , Kosović, B. , Réthoré, P. , Hansen, K. S., Hahmann, A. , Mirocha, J. D. and Rife, D. (2016), Mesoscale to microscale wind farm flow modeling and evaluation. WIREs Energy Environ, 6: e214. doi:10.1002/wene.214

Aplicações Modelamento Mesoescala Setor Eólico

Geosci. Model Dev., 10, 4229–4244, 2017
https://doi.org/10.5194/gmd-10-4229-2017

Geoscientific Model Development
Open Access
EGU

Evaluation of the wind farm parameterization in the Weather Research and Forecasting model (version 3.8.1) with meteorological and turbine power data

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[2]National Renewable Energy Laboratory, Golden, CO, USA

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Received: 25 May 2017 – Discussion started: 8 June 2017
Revised: 22 September 2017 – Accepted: 4 October 2017 – Published: 23 November 2017

Abstract. Forecasts of wind-power production are necessary to facilitate the integration of wind energy into power grids, and these forecasts should incorporate the impact of wind-turbine wakes. This paper focuses on a case study of four diurnal cycles with significant power production, and assesses the skill of the wind farm parameterization (WFP) distributed with the Weather Research and Forecasting (WRF) model version 3.8.1, as well as its sensitivity to model configuration. After validating the simulated ambient flow with observations, we quantify the value of the WFP as it accounts for wake impacts on power production of downwind turbines. We also illustrate with statistical significance that a vertical grid with approximately 12 m vertical resolution is necessary for reproducing the observed power production. Further, the WFP overestimates wake effects and hence underestimates downwind power production during high wind speed, highly stable, and low turbulence conditions. We also find the WFP performance is independent of the number of wind turbines per model grid cell and the upwind–downwind position of turbines. Rather, the ability of the WFP to predict power production is most dependent on the skill of the WRF model in simulating the ambient wind speed.

1 Introduction

In recent years, numerical weather prediction (NWP) models have become an indispensable tool in the wind-energy industry, not only in day-to-day wind-energy production forecasts (Wilczak et al., 2015), but also to support wide-scale wind-power penetration (Marquis et al., 2011) and wind resource assessment. To forecast power production accurately at wind farms, the simulation tools should resolve all physical processes relevant to the wind field, including possible impacts of the wind turbines themselves. Consequently, including the meteorological effects of wind farms in NWP models can improve power-production forecasts.

Researchers have developed various methods to numerically represent wind farms. Via large-eddy simulations (LESs), some investigators assess the meteorological impacts of wind turbines as well as power production (Abkar and Porté-Agel, 2015b; Aitken et al., 2014; Calaf et al., 2010; Churchfield et al., 2012; Jimenez et al., 2007; Mirocha et al., 2014; Na et al., 2016; Sharma et al., 2016; Wu and Porté-Agel, 2011). Simulating wind turbines and their effects in LESs is, while useful, computationally expensive, making wind-farm-scale simulations unreasonable in an operational setting.

At coarser spatial scales, suitable for global, synoptic, or mesoscale models, numerically representing wind turbine effects may involve unrealistic assumptions. For example, researchers have used exaggerated surface roughness to represent the reduction of wind speed (WS) caused by wind farms in a global model (Barrie and Kirk-Davidoff, 2010; Frandsen et al., 2009; Keith et al., 2004). Similarly, the analytical wind park model of Emeis and Frandsen (1993) considers both the downward momentum flux and the momentum loss due to surface roughness. The revised model by Emeis (2010) accounts for the spatially averaged momentum-extraction coefficient by turbines, and the parameters become atmospheric-stability dependent. However, these models omit the consid-

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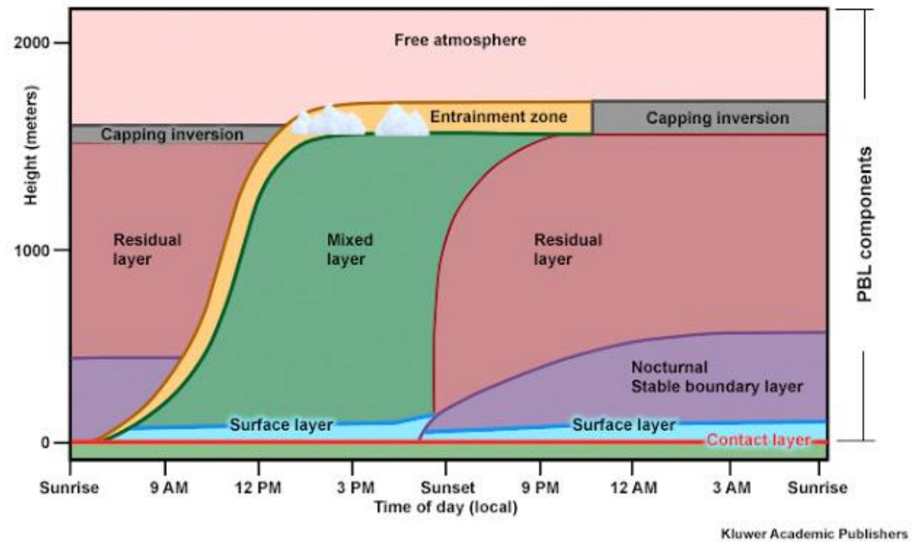
Parameterization	Scheme	Reference
Cumulus	Kain–Fritsch	Kain (2004)
Land surface	NOAH LSM	Ek et al. (2003)
Land surface roughness	Thermal roughness length	Chen and Zhang (2009)
Microphysics	Thompson aerosol-aware	Thompson and Eidhammer (2014)
PBL	MYNN Level 2.5	Nakanishi and Niino (2006)
Radiation	RRTMG	Iacono et al. (2008)



http://ftp.comet.ucar.edu/ootw/tropical/textbook_2nd_edition/print_6.htm

As parametrizações são universais ?
É necessário regionalizar a parametrização ?

Aplicações Modelamento Mesoescala Setor Eólico

Applied Energy 135 (2014) 234–246

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Sensitivity of the WRF model wind simulation and wind energy production estimates to planetary boundary layer parameterizations for onshore and offshore areas in the Iberian Peninsula

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[b] Ephyslab, Facultad de Ciencias, Universidad de Vigo, 32004 Ourense, Spain
[c] CIDEM – Instituto Superior de Engenharia do Porto, Rua Dr. António Bernardino de Almeida 341, 4200-072 Porto, Portugal
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HIGHLIGHTS

- WRF model near surface wind simulation sensitivity to different PBL and SL parameterizations was assessed.
- Simulations were evaluated using onshore and offshore measured data in the Iberian Peninsula.
- ACM2-PX PBL–SL schemes provided the best overall results in terms of wind and wind energy flux simulation.
- QNSE–QNSE PBL–SL schemes presented the best energy flux estimates for offshore areas.
- This study provides valuable guidelines for future offshore and onshore wind energy assessment applications.

ARTICLE INFO

Article history:
Received 13 February 2014
Received in revised form 8 July 2014
Accepted 20 August 2014

Keywords:
WRF
Planetary boundary layer
Parameterizations
Wind energy
Offshore
Onshore

ABSTRACT

This work aims to assess the Weather and Research Forecasting (WRF) model wind simulation and wind energy production estimates sensitivity to different planetary boundary layer parameterization schemes. Five WRF simulations considering different sets of planetary boundary layer (PBL) and surface layer (SL) parameterization schemes were performed, and their results compared to measured wind data collected at five offshore buoys and thirteen onshore wind measuring stations located in the Iberian Peninsula. The objective is to determine which of these model configurations produces wind simulations and wind energy productions estimates closest to measured wind data and wind energy production estimates derived from measurements, aiming to provide guidelines for onshore and offshore wind energy assessment studies focused on areas where measured wind data is not available and numerical modelling is necessary. This work focuses on the Iberian Peninsula, an area with intensive wind energy penetration due to its favourable wind conditions, which combined with its large coastline makes this area a promising one for the future installation of offshore wind farms.

The results presented in this work show that, although no major differences are seen among the simulations in terms of wind speed and direction simulation accuracy, in terms of wind energy production estimates the differences are not negligible due to the high sensitivity of the wind energy production to the wind simulation accuracy. The PBL–SL parameterization set composed by the schemes ACM2-PX is the one with the lowest errors when compared to observed wind data, when considering all onshore and offshore sites together. The ACM2 PBL scheme combines features of local and non-local closure schemes and the PX LSM scheme provides a better parameterization of the surface meteorology, which proved to be important in the model performance. However, for offshore sites the PBL–SL parameterizations QNSE–QNSE produced the best wind energy production estimates.

Due to the close dependence of each PBL and SL scheme performance on the surrounding synoptic conditions and atmospheric stability, it is expected that for different geographical areas and/or temporal

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http://dx.doi.org/10.1016/j.apenergy.2014.08.082

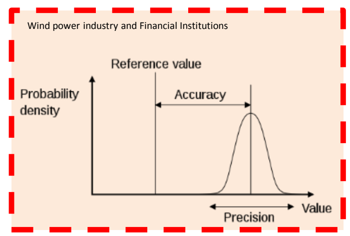
Table 2
Physical configuration of the simulations.

Simulation	YMN	MEN	APP	QQN	MMN
SL	MM5	ETA	PX	QNSE	MYNN
PBL	YSU	MYJ	ACM2	QNSE	MYNN-2.5
LSM	Noah		PX	Noah	
Long-wave radiation			RRTM		
Short-wave radiation			Dudhia		
Cumulus			Kain-Fritsch		
Microphysics			WSM6		

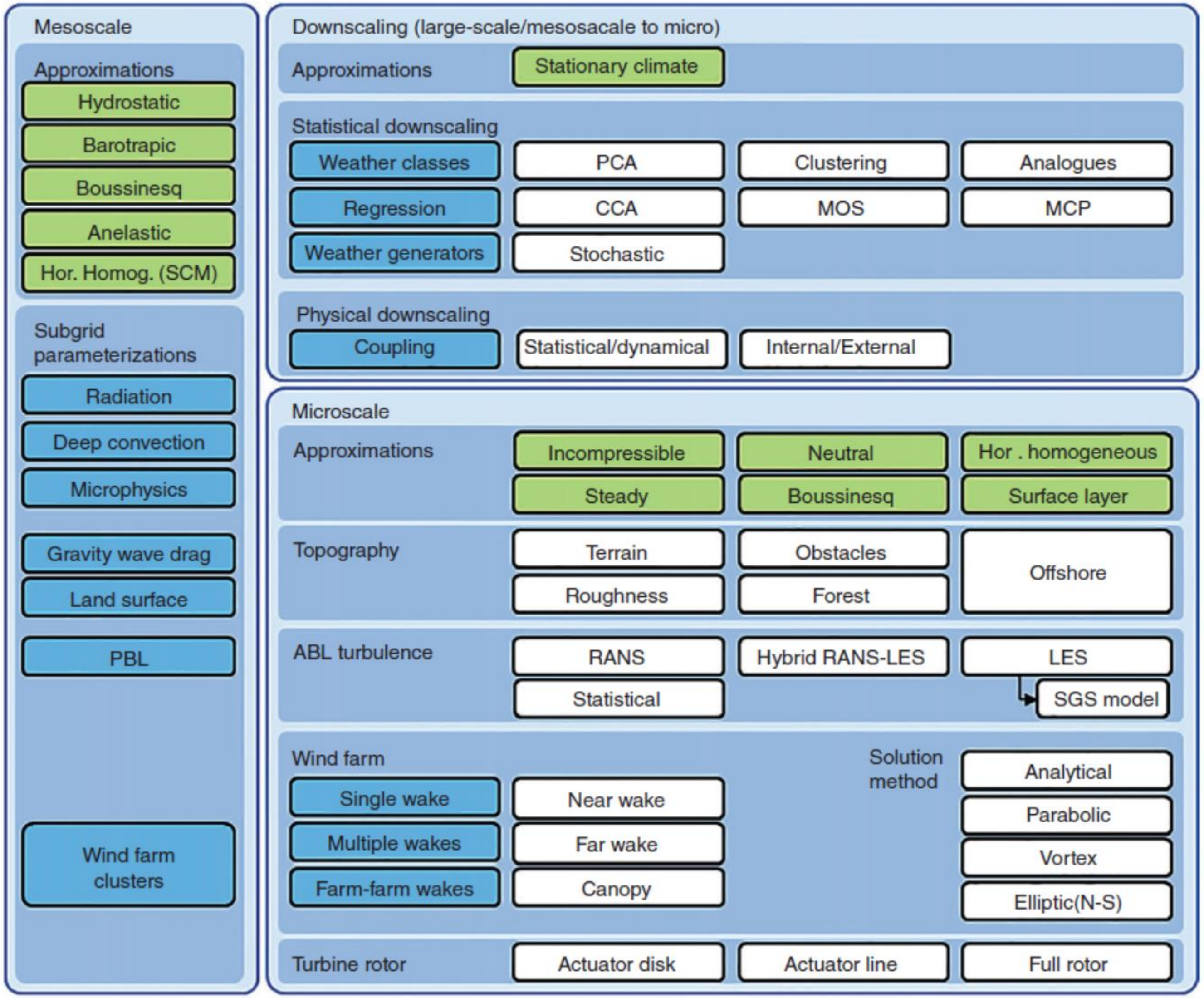
Table 3
Statistics of the comparison between observed and simulated wind data.

Area	Simulation	RMSE		Bias		STDE		R	
		Speed (ms^{-1})	Direction (°)	Speed (ms^{-1})	Direction (°)	Speed (ms^{-1})	Direction (°)	Speed (ms^{-1})	Direction (°)
Offshore	YMN	1.85	38.59	0.48	3.41	1.78	38.36	**0.88**	0.83
	MEN	1.86	38.56	0.41	1.94	1.81	38.44	**0.88**	0.83
	APP	**1.83**	**38.07**	0.46	2.31	**1.76**	**37.93**	**0.88**	**0.84**
	QQN	1.86	38.19	**0.35**	**1.81**	1.82	38.01	0.87	0.83
	MMN	1.91	39.09	0.57	4.08	1.82	38.81	0.87	0.83
Onshore	YMN	2.10	**35.02**	0.34	−0.35	2.02	**34.87**	0.79	**0.78**
	MEN	2.03	35.55	**0.11**	−0.77	1.96	35.43	0.79	0.77
	APP	**1.91**	35.72	−0.17	−2.53	**1.88**	35.48	**0.80**	**0.78**
	QQN	2.19	37.68	0.26	−0.07	2.10	37.56	0.75	0.72
	MMN	2.02	35.53	0.18	**0.03**	1.96	35.39	0.79	0.77
All sites	YMN	1.97	**36.81**	0.41	1.53	1.90	**36.61**	0.83	**0.81**
	MEN	1.94	37.06	0.26	0.59	1.88	36.94	0.83	0.80
	APP	**1.87**	36.89	**0.14**	**−0.11**	**1.82**	36.71	**0.84**	**0.81**
	QQN	2.03	37.93	0.31	0.87	1.96	37.79	0.81	0.78
	MMN	1.97	37.31	0.38	2.05	1.89	37.10	0.83	0.80

Importância da validação para academia e indústria



Taxionomia de métodos de downscaling para microescala



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CAMARGO SCHUBERT

Protocolo para avaliação de modelos em microescala

iea wind

WAKEBENCH Model Evaluation Protocol for Wind Farm Flow Models

First Edition

Edited by:
Javier Sanz Rodrigo
National Renewable Energy Centre of Spain (CENER)

Patrick Moriarty
National Renewable Energy Laboratory (NREL)

IEA-Wind Task 31
April 2015

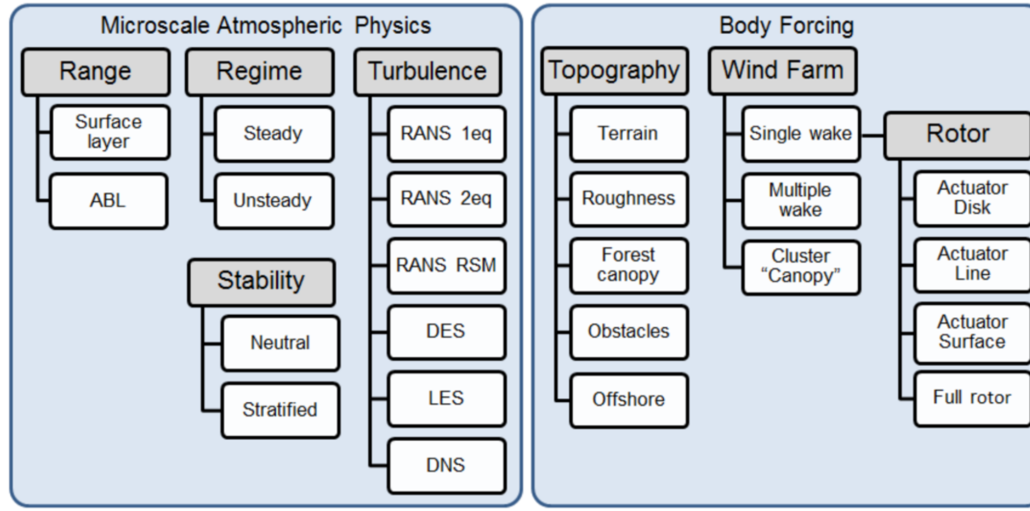

Figure 1: Diagram for microscale wind farm model classification.

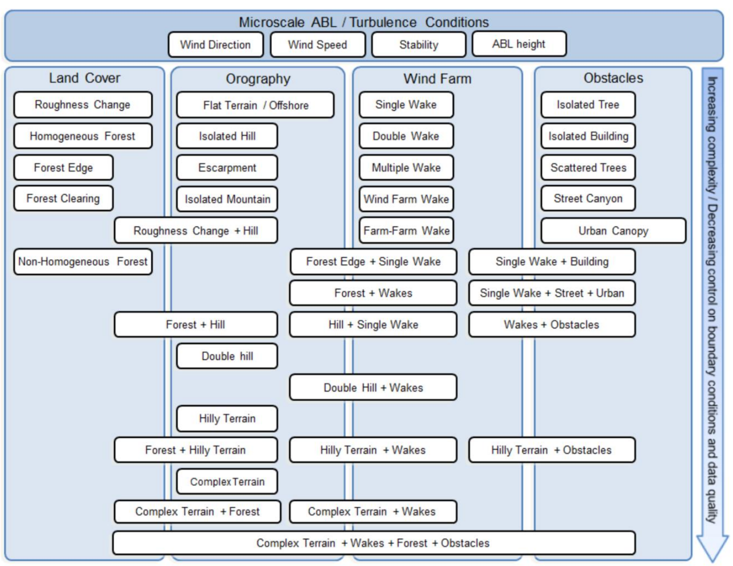

Figure 5: Schematic of the building-block approach applied to wind farm flow models.

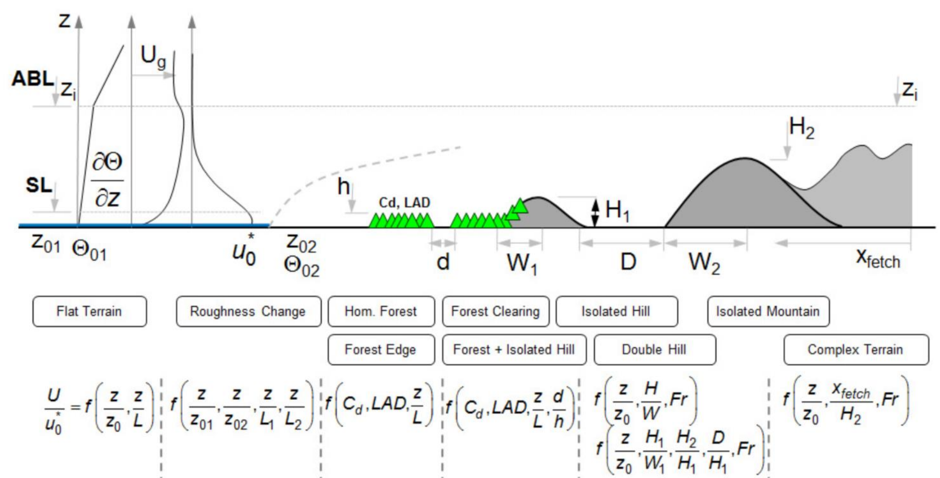

Figure 6: Schematic of parametric building-blocks building up to define a complex system. *L* is the Obukhov length, *Fr* is the Froude number, z_i is the boundary layer height, Θ is the potential temperature, U_g is the geostrophic wind, *SL* indicates the surface layer, *LAD* is the leaf-area index, z_0 is the roughness length, u_* is the friction velocity. *f(x)* is any variable of interest that can be described based on a set of dimensionless scaling parameters.

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CAMARGO SCHUBERT

Porque a modelagem numérica da atmosfera é um desafio...

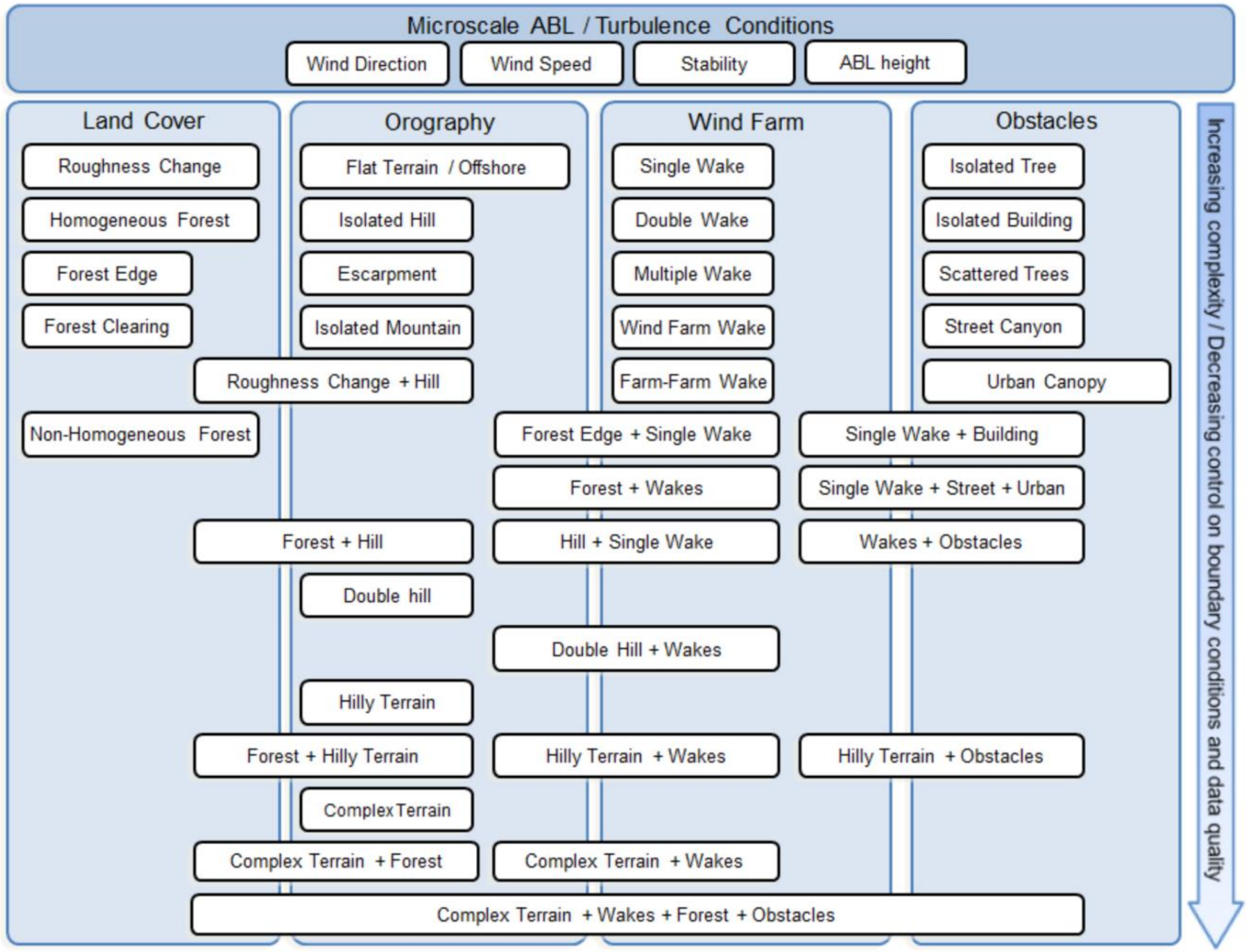
iea wind

WAKEBENCH Model Evaluation Protocol for Wind Farm Flow Models
First Edition

Edited by:
Javier Sanz Rodrigo
National Renewable Energy Centre of Spain (CENER)

Patrick Moriarty
National Renewable Energy Laboratory (NREL)

IEA-Wind Task 31
April 2015



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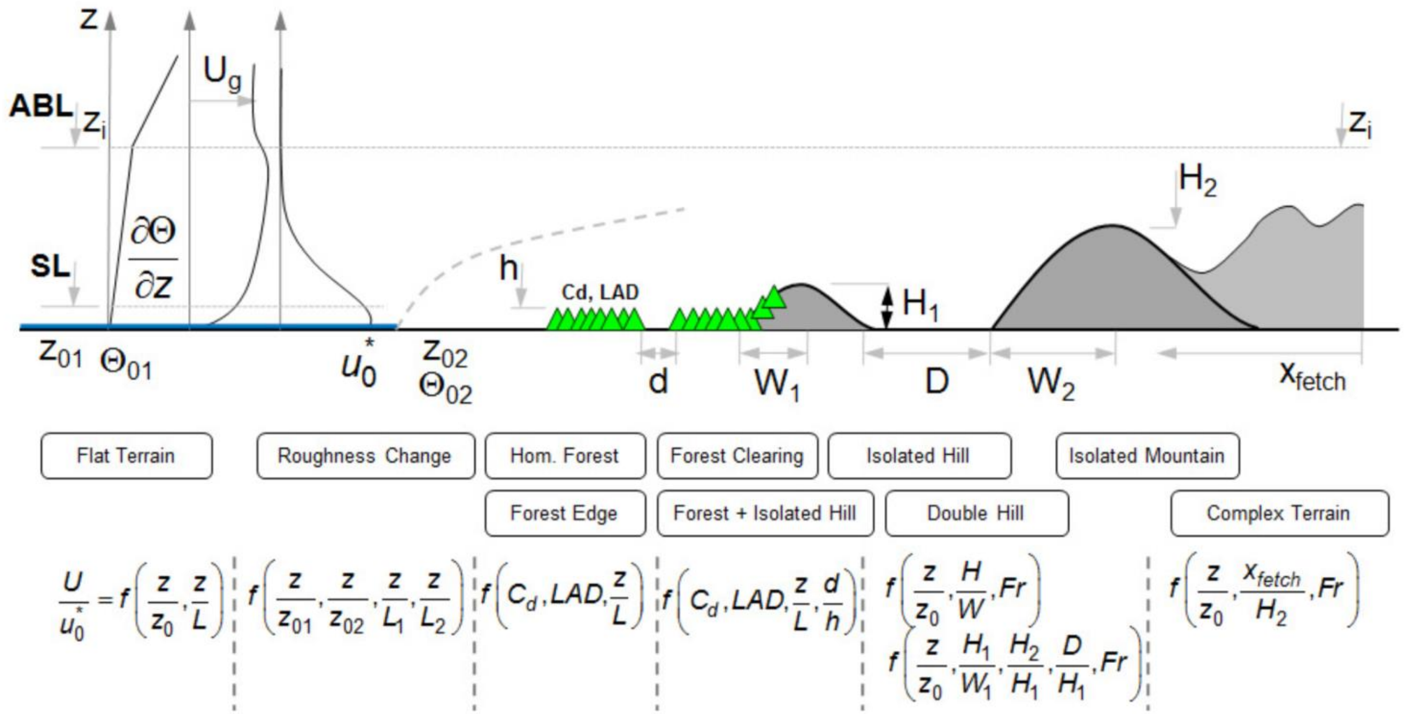

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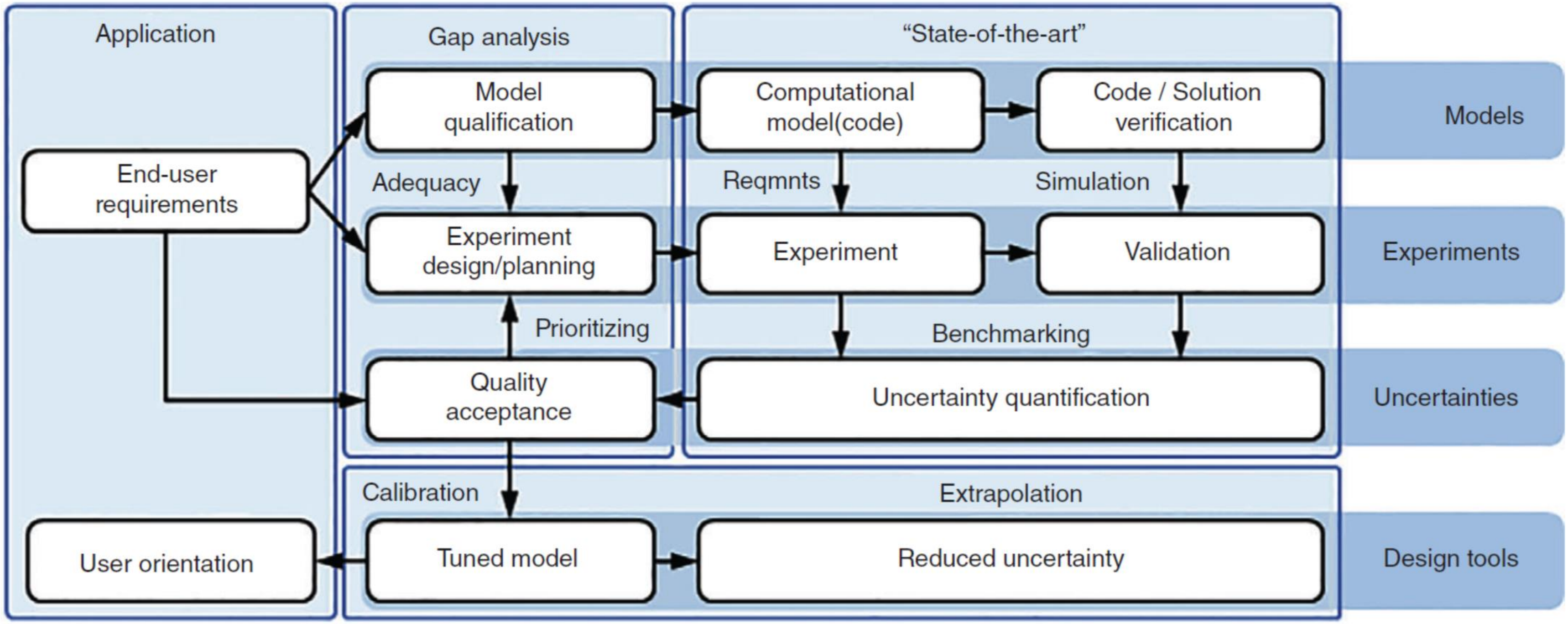
Diagrama de Avaliação dos Modelos e Definição do Estado da Arte



Sanz Rodrigo, J. , Chávez Arroyo, R. A., Moriarty, P. , Churchfield, M. , Kosović, B. , Réthoré, P. , Hansen, K. S., Hahmann, A. , Mirocha, J. D. and Rife, D. (2016), Mesoscale to microscale wind farm flow modeling and evaluation. WIREs Energy Environ, 6: e214. doi:10.1002/wene.214

Camargo Schubert

No mundo real temos medições que precisam ser espacializadas...

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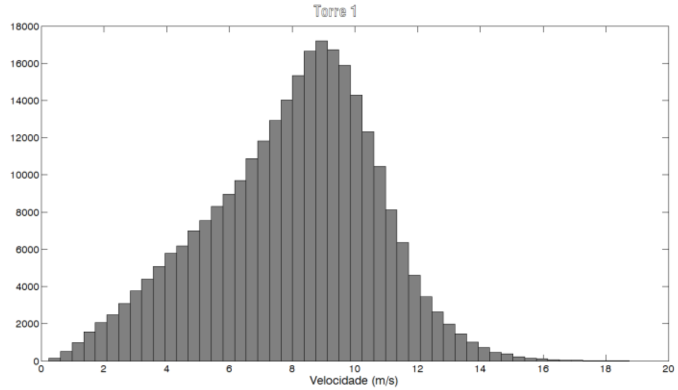
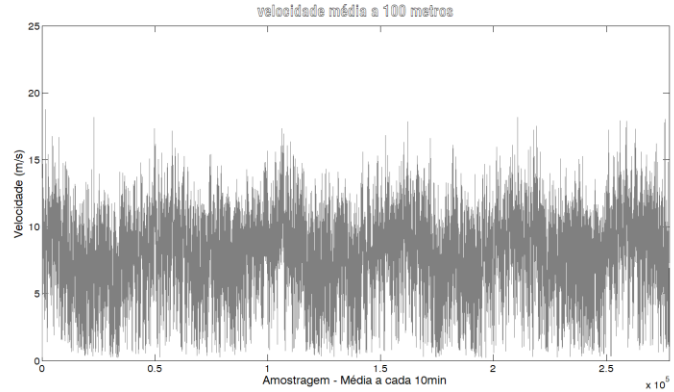
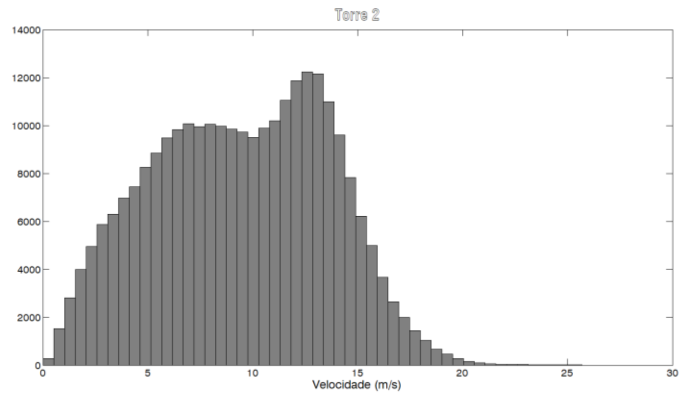
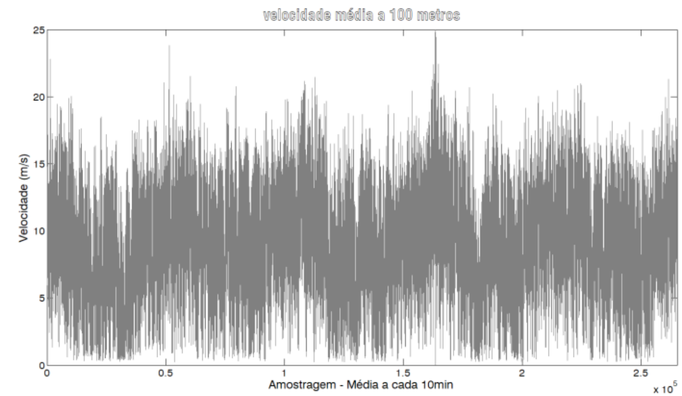
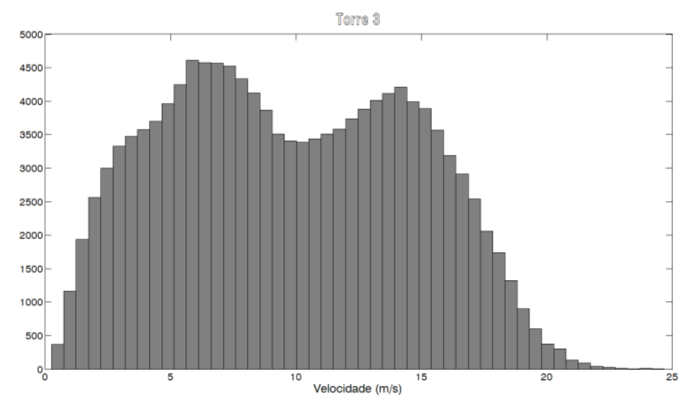
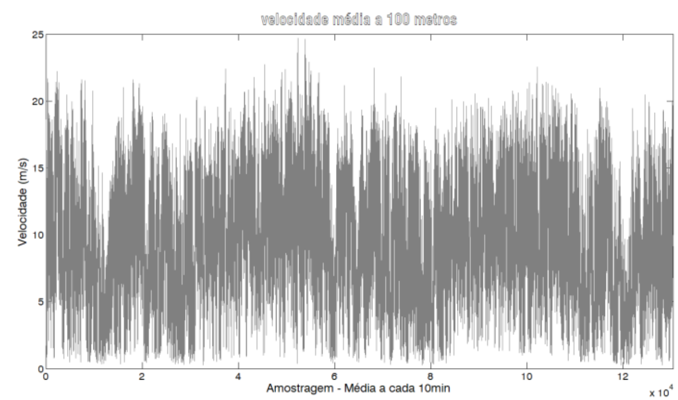




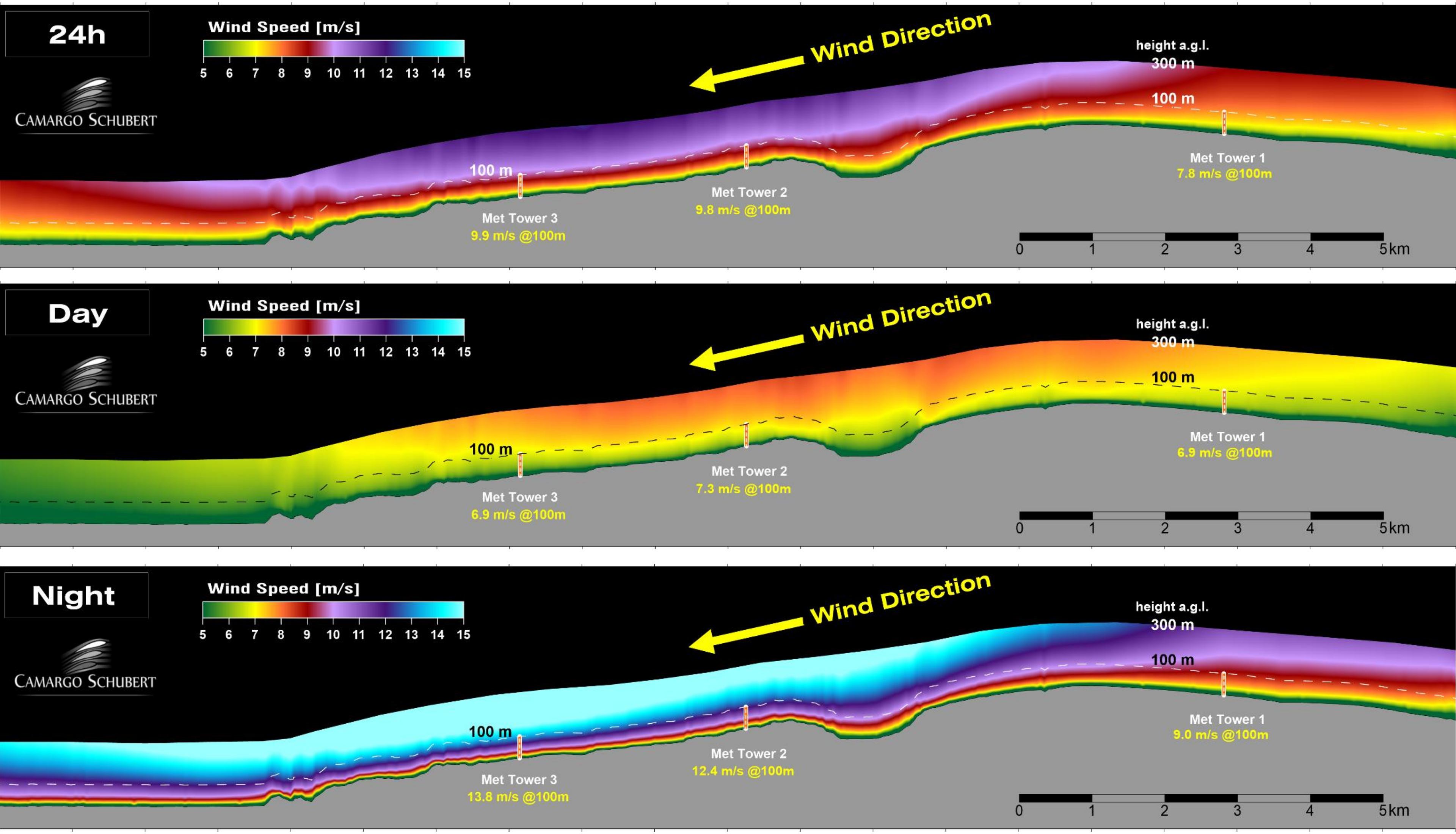








Importância de estudar os regimes dia-noite no interior do Nordeste brasileiro



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O acoplamento Mesoescala para Microescala

Brower, Michael C.. "4.2 Mesoscale Modeling as a Tool for Wind Resource Assessment and Mapping." (2003).

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Os erros e validação no processo de modelagem do vento...

WIND FLOW MODEL PERFORMANCE

Do more sophisticated models produce more accurate wind resource estimates?

Philippe Beaucage, Research Scientist
Michael C. Brower, Chief Technical Officer

February 6, 2012

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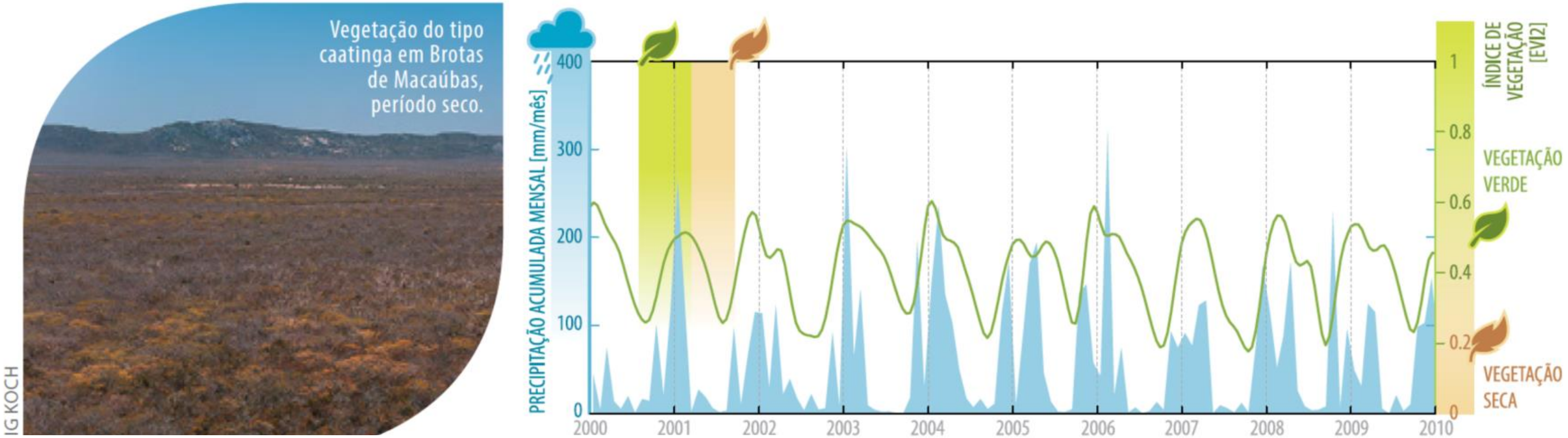
	Site				
	1	2	3	4	Combined
Terrain	Flat	Complex	Complex	Complex	
Land Cover	Mixed	Open	Forested	Forested	
Number of Masts	8	6	3*	9	26
Mean Distance Between Masts	7.3 km	5.0 km	5.7 km	6.0 km	
	RMSE (m/s)				
Linear Jackson-Hunt model	0.26	0.34	1.15	0.74	0.62
CFD model	0.50	0.46	1.07	0.95	0.76
Mass-consistent model	0.32	0.26	0.75	0.76	0.56
Coupled NWP and mass-consistent model	0.10	0.39	0.56	0.67	0.48
Coupled high-res NWP and mass-consistent model	0.24	0.30	0.59	0.63	0.46
NWP/LES model	0.28	0.49	0.57	0.49	0.45

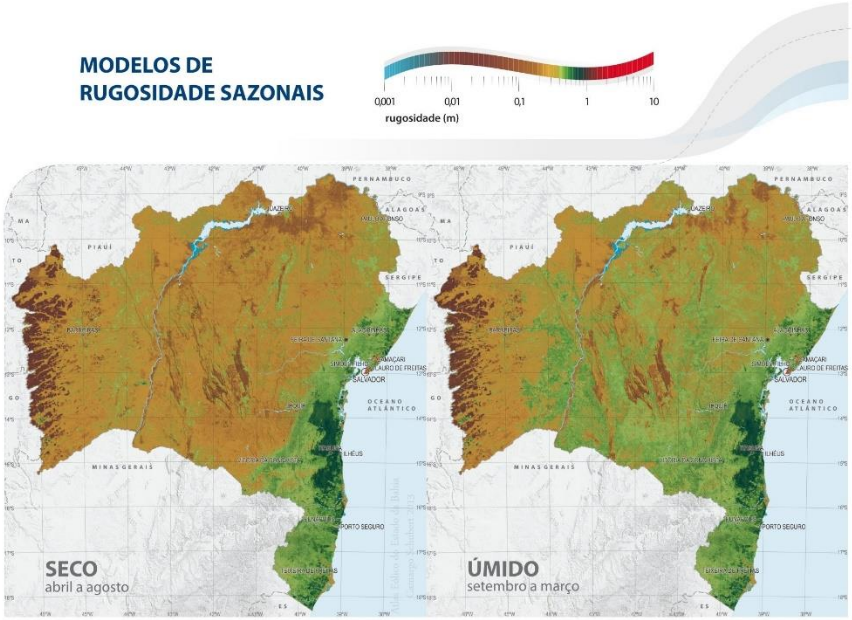
CAMARGO SCHUBERT

A variabilidade da velocidade do vento com alteração da rugosidade aerodinâmica ("importância de observar antes de rodar")

A variabilidade da Rugosidade Aerodinâmica ao longo do ano

EXEMPLO DE VARIAÇÃO INTERANUAL DA VEGETAÇÃO EM UMA ÁREA DE CAATINGA



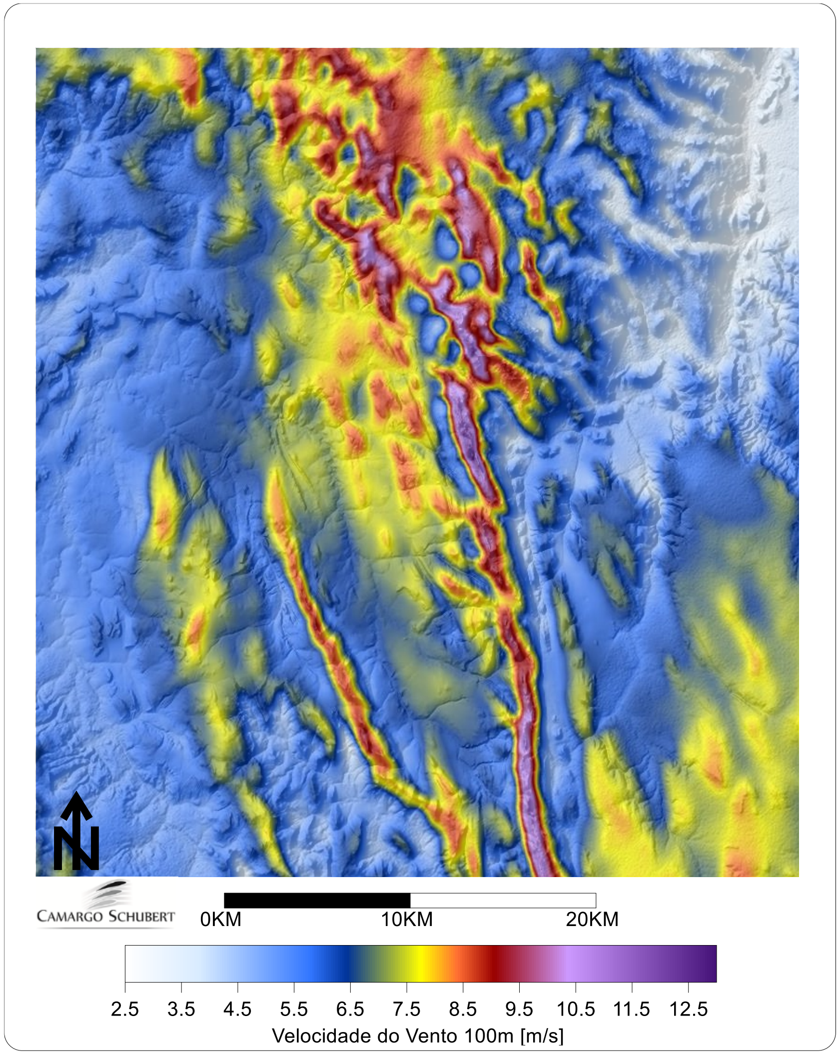


Tipo de Cobertura e/ou Uso da Terra	Faixa de Rugosidade z_0 [m]
Áreas urbanas	0,4 – 3,0
Florestas	0,4 – 0,8
Caatinga	0,1 – 0,4
Cerrado	0,1 – 0,4
Culturas agrícolas	0,02 – 0,1
Pastagens	0,02 – 0,05
Solo exposto	0,001 – 0,01
Corpos d'água (lagos, oceano) (sem vento de superfície)	0,0002 – 0,001

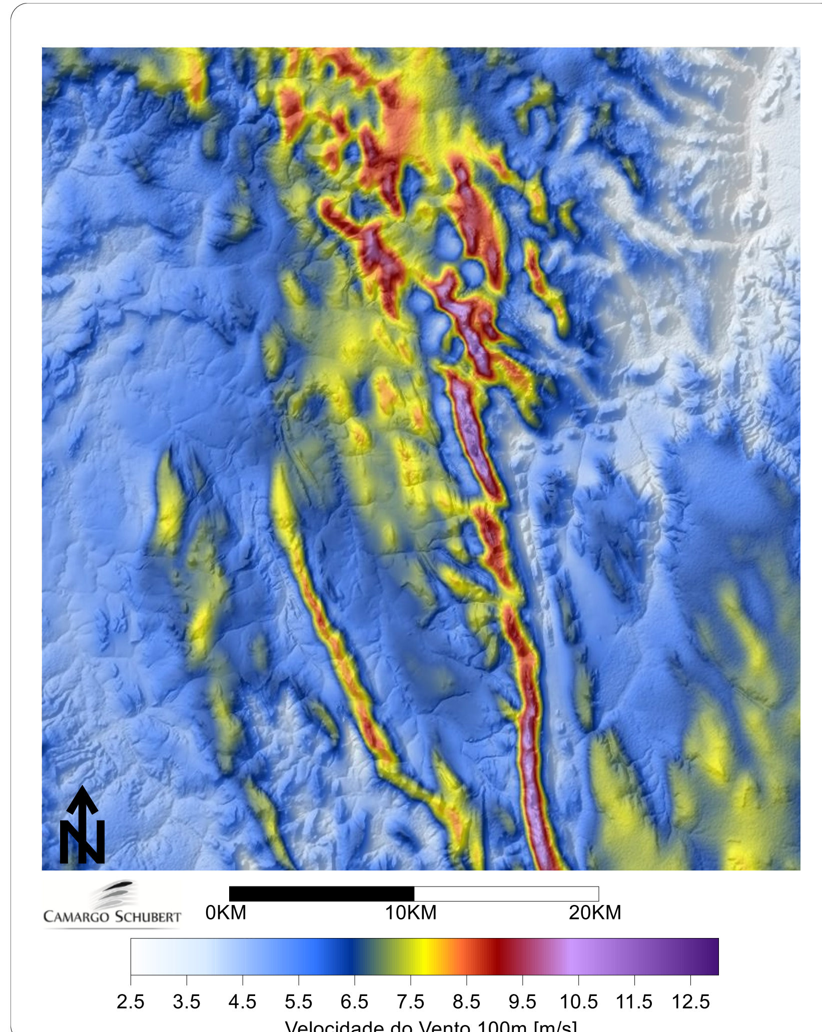
Exemplo da variabilidade da rugosidade

Cenários

50% Menor Rugosidade



50% Maior Rugosidade



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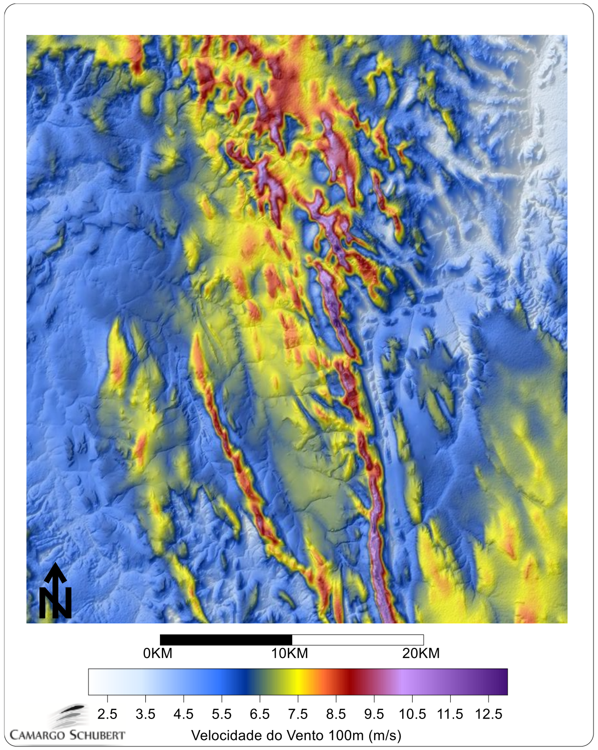
Incrementos ou decrementos % da velocidade do vento

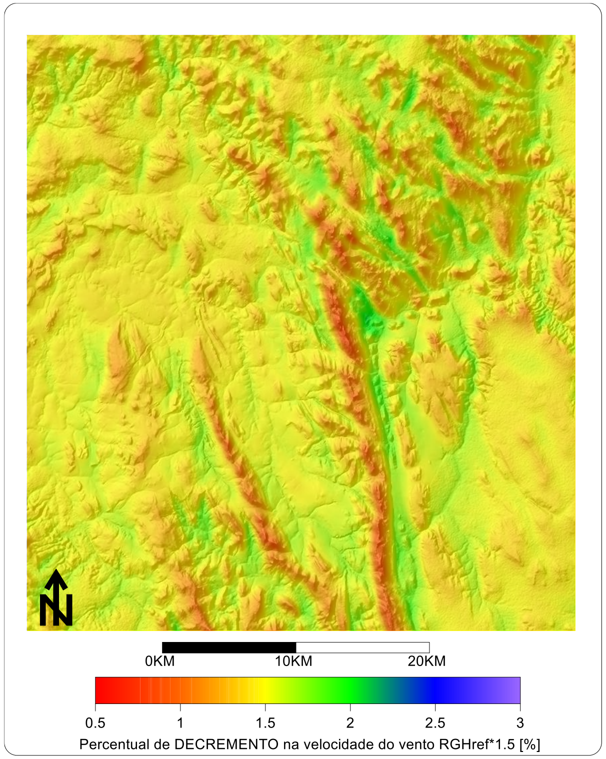
Cenários

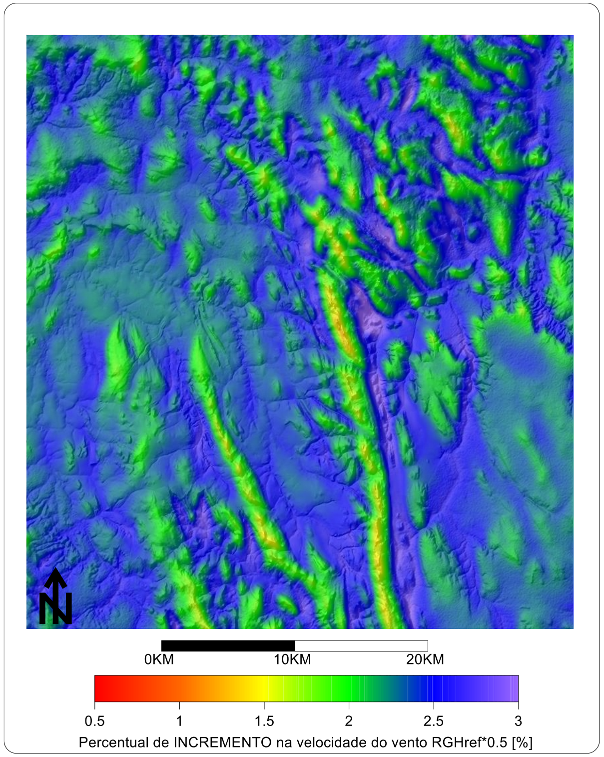
Rugosidade Média

50% Maior Rugosidade

50% Menor Rugosidade



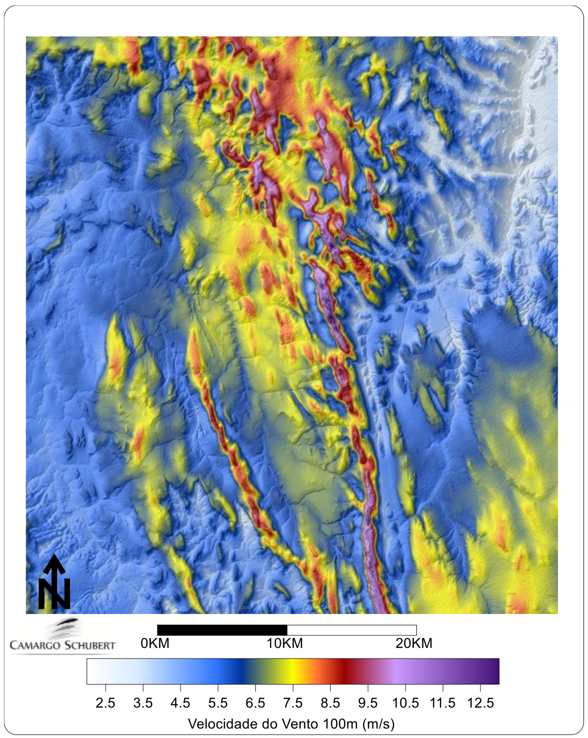




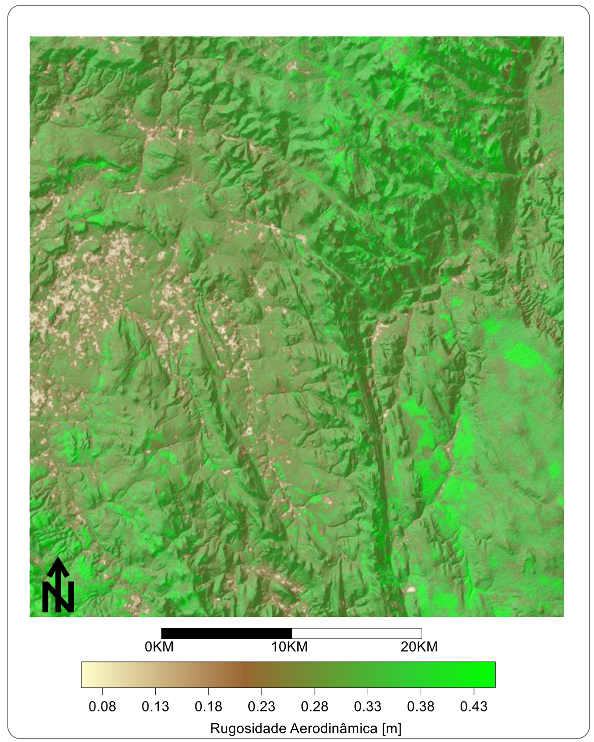
A importância de mapear rugosidade em microescala

- Podem ocorrer alterações no uso e cobertura da terra
- A importância de modelos de rugosidade consistentes com a realidade
- Erros de mapeamento de rugosidade podem comprometer a viabilidade de projetos

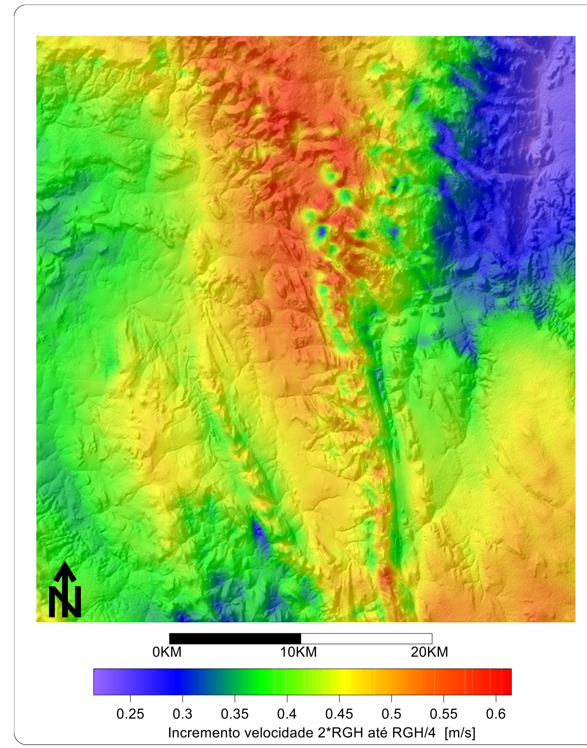
Velocidade



Rugosidade Média



Amplitude da Rugosidade
(erros de mapeamento)



A Variabilidade espacial da estabilidade

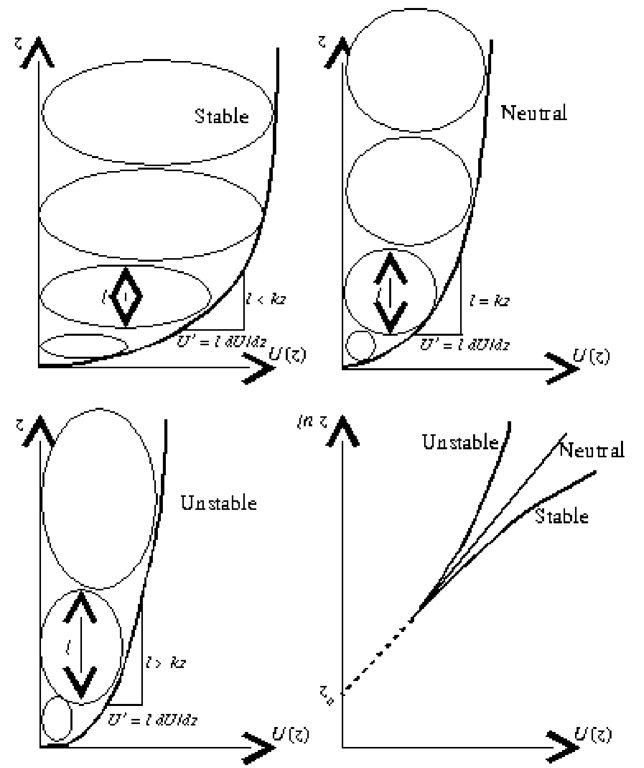
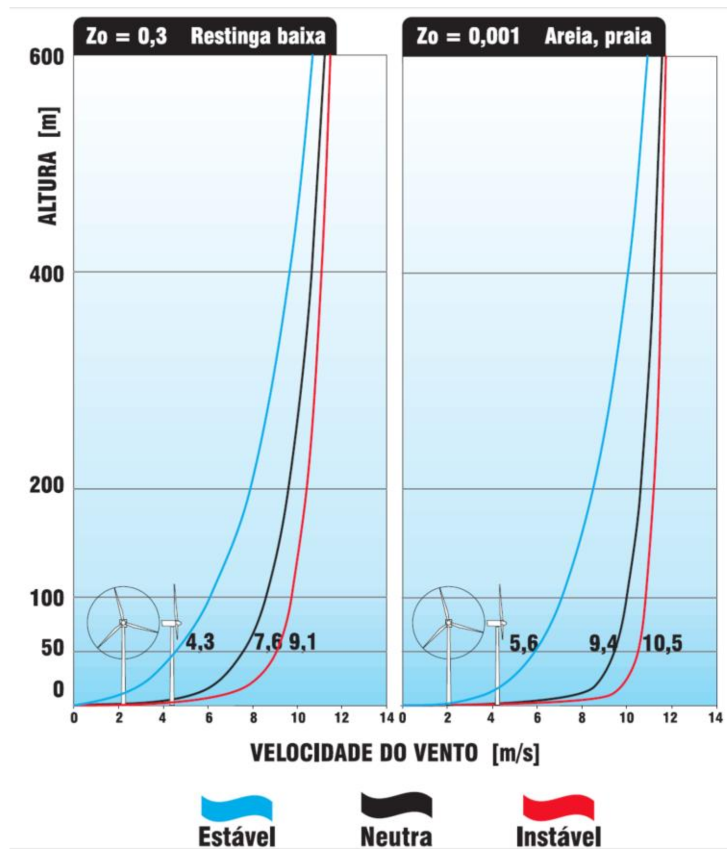


Figure 1. Wind speed profiles and conceptual eddy structures of the three stability types in near surface flow (after Thom, 1975).



Thom, A. S.: Momentum, mass and heat exchange of plant commu-
nities, In: Monteith, J.L. Vegetation and the Atmosphere, Aca-demic Press, London, 57–109, 1975.

A Importância da Estabilidade Atmosférica na Eólica

LLNL-TR-424425

LAWRENCE LIVERMORE NATIONAL LABORATORY

Atmospheric Stability Impacts on Power Curves of Tall Wind Turbines - An Analysis of a West Coast North American Wind Farm

S. Wharton, J. K. Lundquist

February 23, 2010

Stability class	L (m)	α	I_{U_80}	TKE_{80} ($m^2 s^{-2}$)	Boundary layer properties	Frequency			
						W	Sp	Su	A
strongly stable	$0 < L < 50$	$\alpha > 0.3$	$I_U < 8\%$	$TKE < 0.4$	Highest shear in swept-area, nocturnal LLJ may be present, little turbulence except just below the LLJ	11%	19%	22%	4%
stable	$50 < L < 200$	$0.2 < \alpha < 0.3$	$8\% < I_U < 10\%$	$0.4 < TKE < 0.6$	High wind shear in swept-area, low amount of turbulence	25%	32%	35%	30%
neutral	$L > 200$ or $L < -300$	$0.1 < \alpha < 0.2$	$10\% < I_U < 20\%$	$0.6 < TKE < 1.0$	Generally strongest wind speeds throughout the blade swept-area	27%	30%	22%	26%
convective	$-300 < L < -15$	$0.0 < \alpha < 0.1$	$20\% < I_U < 30\%$	$1.0 < TKE < 1.4$	Lower wind speeds, low shear in swept-area, high amount of turbulence	17%	15%	14%	20%
strongly convective	$-15 < L < 0$	$\alpha < 0.0$	$I_U > 30\%$	$TKE > 1.4$	Lowest wind speeds, very little wind shear in swept-area, highly turbulent	20%	4%	7%	20%

Table 2: Stability classifications for the four stability parameters (Obukhov length, wind shear, turbulence intensity, and turbulence kinetic energy), general atmospheric conditions, and frequency of occurrence during the data period. Wind shear, turbulence intensity and turbulence kinetic energy thresholds are based on the SODAR wind velocity data.

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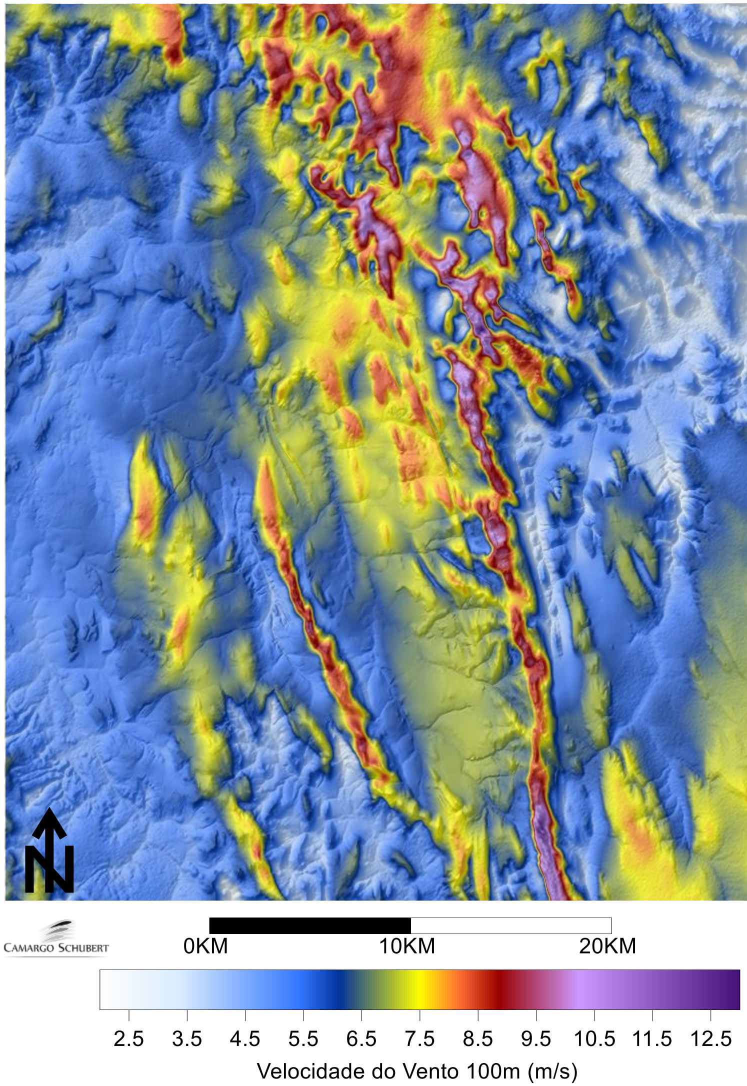
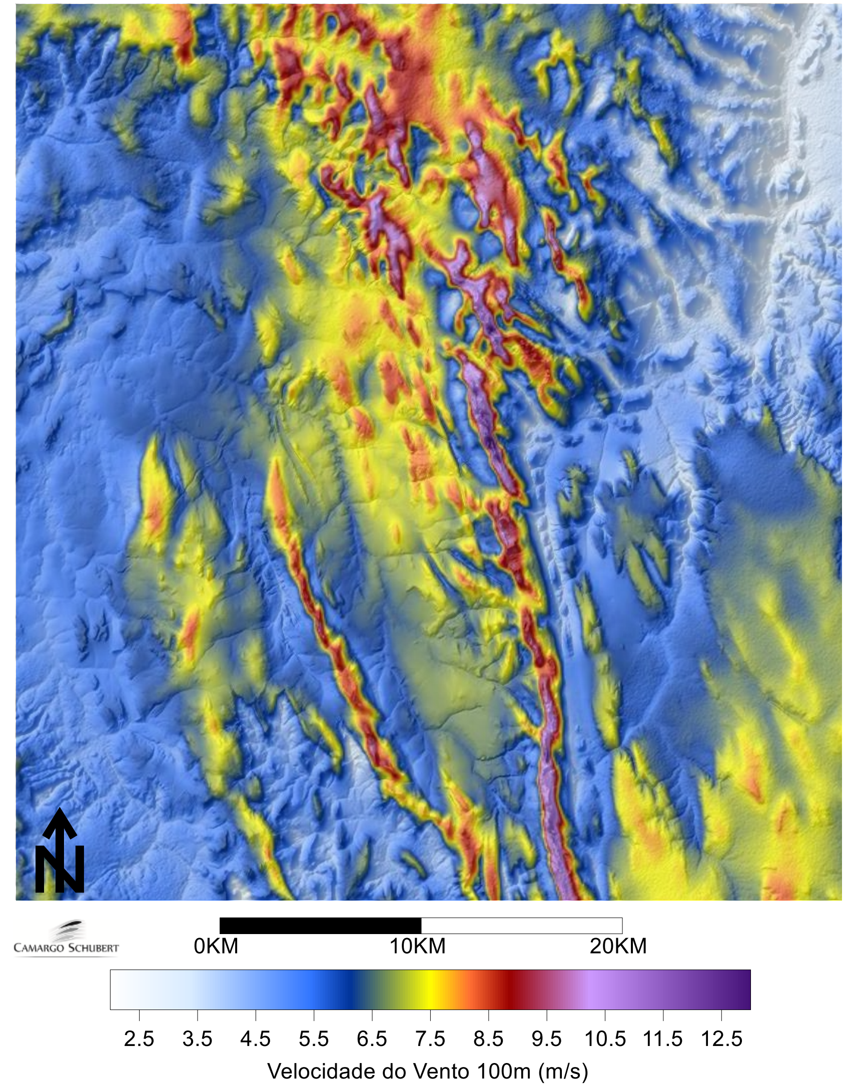
A distribuição espacial do vento para diferentes estabilidades

L muito estável (L=50)



L estável (L100)



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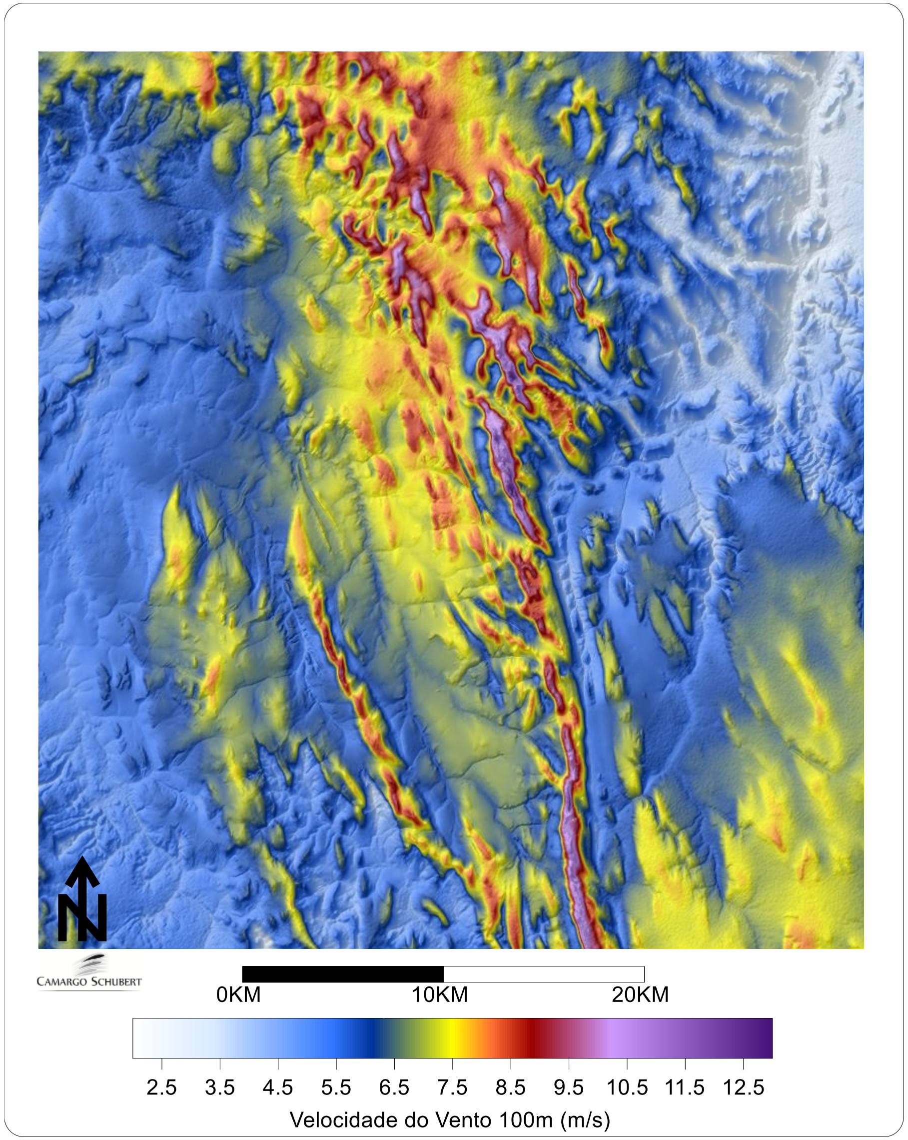
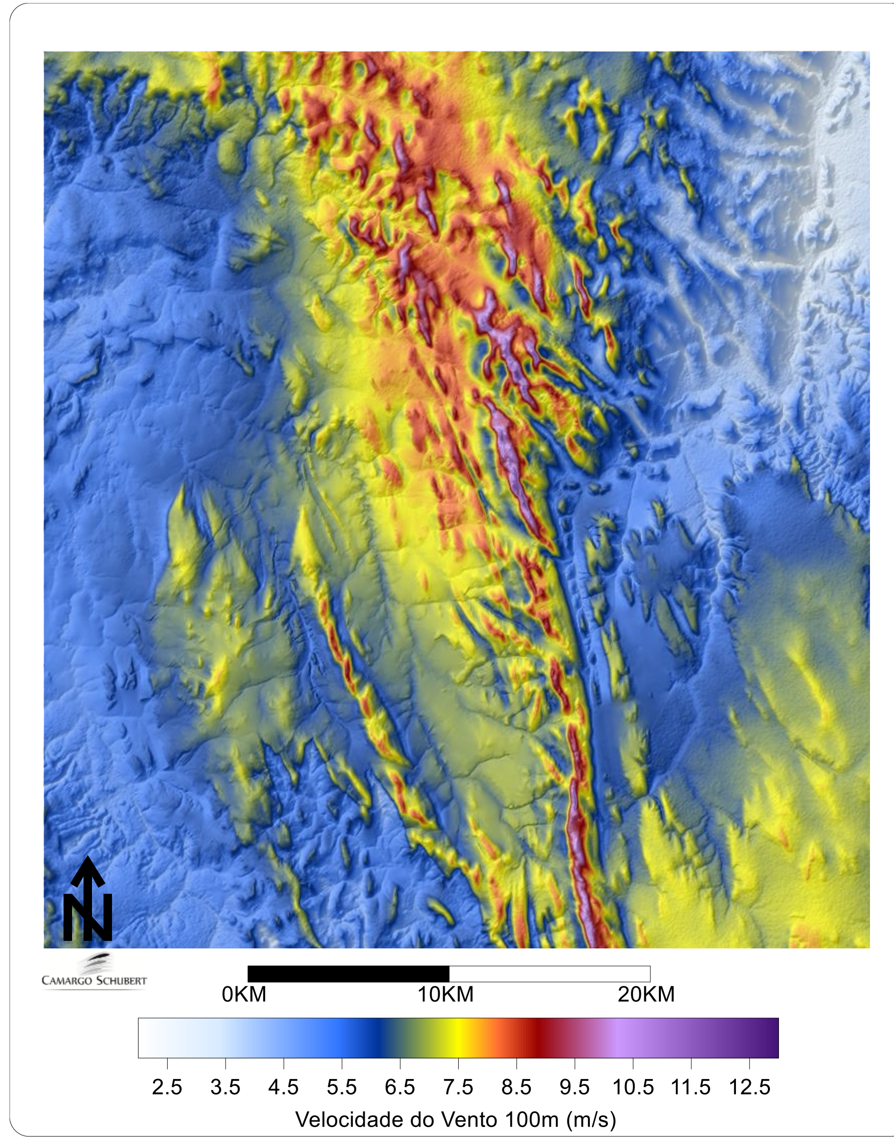
A distribuição espacial do vento para diferentes estabilidades

L quase estável (L250)



L neutro (L750)



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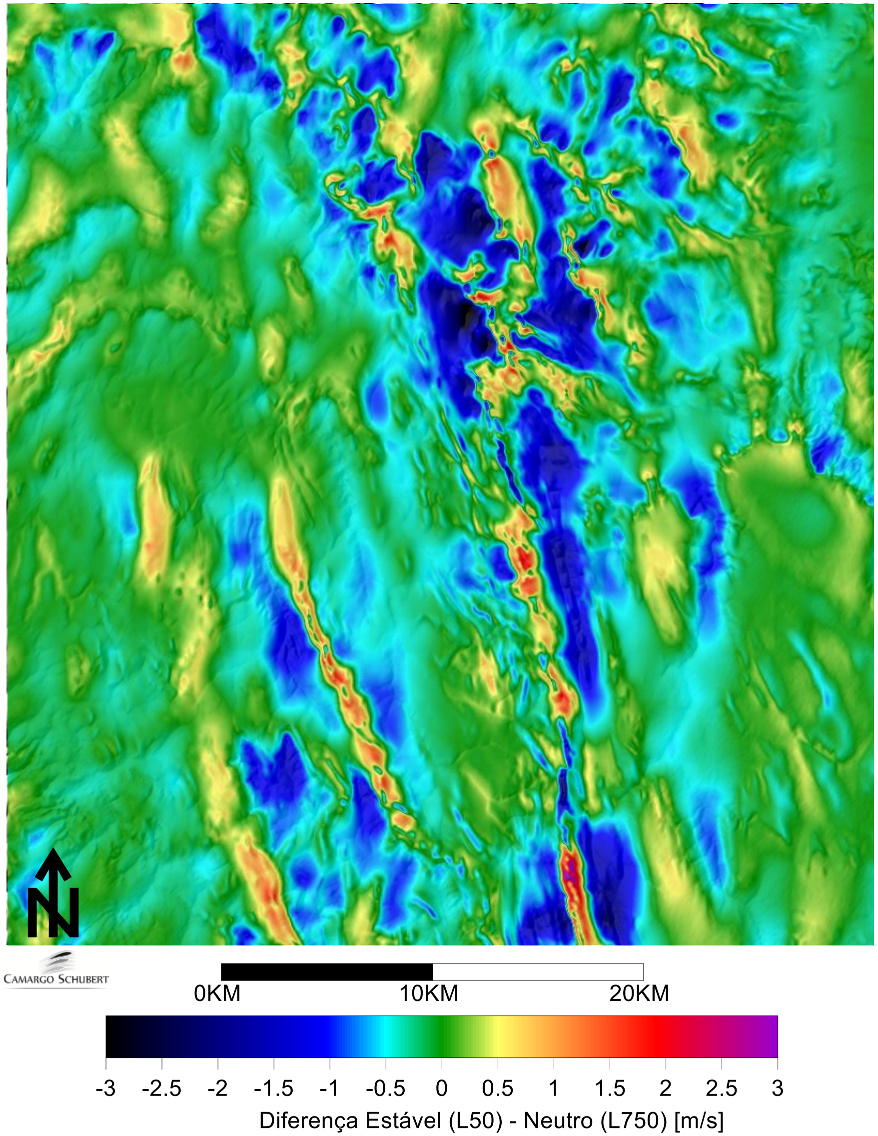
Diferença Estável (L=50) – Neutro(L=750)



A Importância da Topografia na Modelagem Atmosférica

Numerical Evaluation of Wind Flow over Complex Terrain: Review

G. T. Bitsuamlak[1]; T. Stathopoulos, F.ASCE[2]; and C. Bédard[3]

Abstract: This paper reviews the current state of the art in the numerical evaluation of wind flow over different types of topographies. Numerical simulations differing from one another by the type of numerical formulation followed, the turbulence model used, the type of boundary conditions applied, the type of grids adopted, and the type of terrain considered are summarized. A comparative study among numerical and experimental (both wind tunnel and field) existing works establishing the modifications of wind flow over hills, escarpments, valleys, and other complex terrain configurations demonstrates generally good predictions on the upstream but problematic predictions on the downstream areas of the complex terrain. Comparisons are also made with provisions of the current wind standards as well as with speed-up values calculated using guidelines derived from theoretical models.

DOI: 10.1061/(ASCE)0893-1321(2004)17:4(135)

CE Database subject headings: Wind loads; Computational fluid dynamics technique; Turbulence; Terrain; Topography.

Introduction

Wind pressures on buildings and other structures, pedestrain level winds, wind-induced dispersion of pollutants in urban locations depend, among other factors, on the velocity profile and turbulence characteristics of the upcoming wind. These, in turn, depend on the roughness and general configuration of the upstream terrain. Consequently, wind standards and codes of practice typically assume upstream terrain of homogeneous roughness or provide explicit corrections for specific topographies such as hills or escarpments; for more complex situations they refer the practitioner to physical simulation in a boundary layer wind tunnel (BLWT). The evolution of computational wind engineering makes the evaluation of wind velocities over complex terrain very attractive. In fact, significant progress has been made in the application of computational fluid dynamics (CFD) for specific cases of the evaluation of wind flow over escarpments, single and multiple hills, as well as valleys. Numerical modeling of wind flow consists of utilizing a set of differential equations (Navier-Stokes) describing the flow in a particular domain, say near an obstruction. The Reynolds-averaged Navier-Stokes (RANS) equations have been used in most of the studies dealing with wind flow over complex terrain. Turbulence of the flow is represented by a particular model, such as the well-known k-ε model, which is appropriate only for the case of homogeneous isotropic turbulence. Discretization of the flow equations leads to a set of solvable algebraic equations. The simplification inherent in the use of algebraic equations together with the fast growth in computer technology is what makes the numerical approach capable of solving more complex, realistic problems than before at reasonable cost. This paper presents and discusses the progress made in the numerical evaluation of wind flow over complex topographies and compares computational results with experimental data. The emphasis is placed on the evaluation of velocity ratios since wind-induced pressures are proportional to the square of the wind speeds. Consequently, a small variation of wind speed due to the upstream topography may have a large influence on the loading of the structures. Hills, escarpments, valleys, and more complex terrain conditions have been considered.

Single Two-Dimensional Hills and Escarpments

Field measurement results and experimental data from BLWT physical simulations have been compared with CFD predictions and provisions of the National Building Code of Canada [NBCC (1995)] for a number of geometries and roughnesses. It should be noted that the code provisions have also been used by the American wind load standard ASCE 7 in all its recent editions, as well. Figs. 1 and 2 compare typical results for the variation of velocity profiles above several geometries of escarpments and on hilltops respectively. Data has been gathered from literature but they are recalculated and reformatted in order to fit in the same graph for comparison purposes. For different geometries of escarpments (H/L=0.2 to 1.2) and hills (H/L=0.2 to 0.6), as well as different values of upstream roughness expressed by Jensen's number (H/z_o) ranging from 400 to 40,000, normalized speed-up ratio values given by $[\Delta u(z)L]/[u_o(2L)H]$ for escarpments and $[\Delta u(z)L]/[u_o(L)H]$ for hills are quite similar. In these expressions H represents the height of the hill/escarpment, L represents the

[1]Graduate Student, Centre for Building Studies, Dept. of Building, Civil and Environmental Engineering, Concordia Univ., 1257 Guy St., 341 Montreal PQ, Canada, H3H 1H5. E-mail:gtsegaye@cbs-engr.concordia.ca

[2]Professor and Associate Dean Graduate Studies, Centre for Building Studies, Dept. of Building, Civil and Environmental Engineering, Concordia Univ., 1257 Guy St., 341 Montreal PQ, Canada, H3H 1H5. E-mail:statho@cbs-engr.concordia.ca

[3]Professor and Dean of Research and Technology Transfer, École de technologie supérieure, 1100 Notre-Dame W. Montreal PQ, Canada, H3C 1K3. E-mail: claude.bedard@etsmtl.ca

Note. Discussion open until March 1, 2005. Separate discussions must be submitted for individual papers. To extend the closing date by one month, a written request must be filed with the ASCE Managing Editor. The manuscript for this paper was submitted for review and possible publication on April 18, 2003; approved on December 23, 2003. This paper is part of the *Journal of Aerospace Engineering*, Vol. 17, No. 4, October 1, 2004. ©ASCE, ISSN 0893-1321/2004/4-135–145/$18.00.

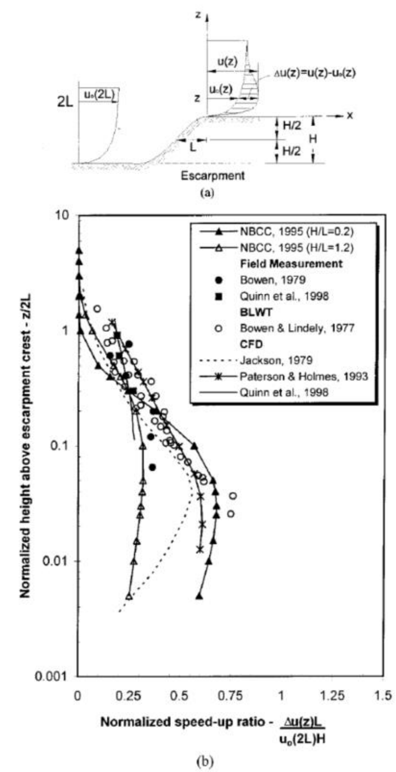


Fig. 1. Escarpment: (a) Definitions of parameters; and (b) dimensionless velocity speed-up factors (Bowen 1979; Bowen and Lindely 1977; Jackson 1979)

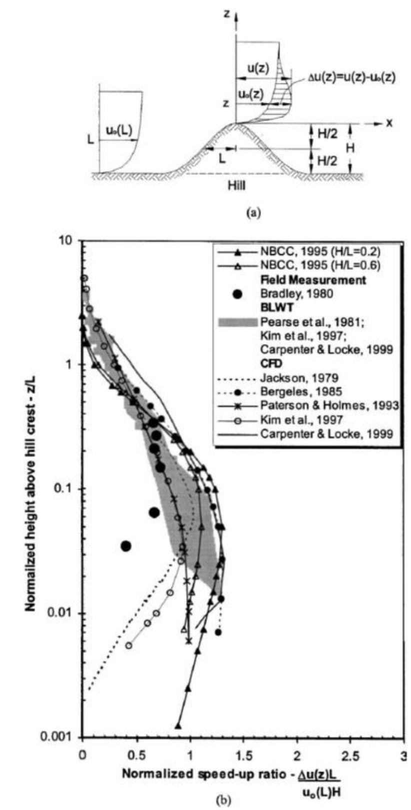
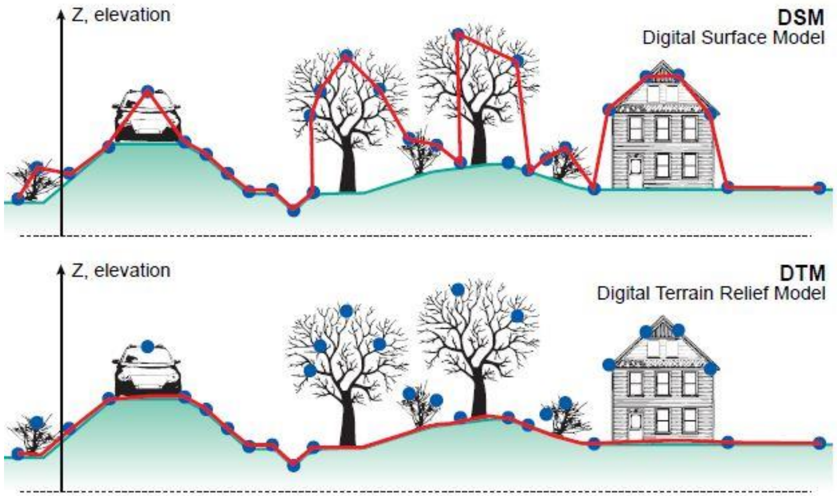
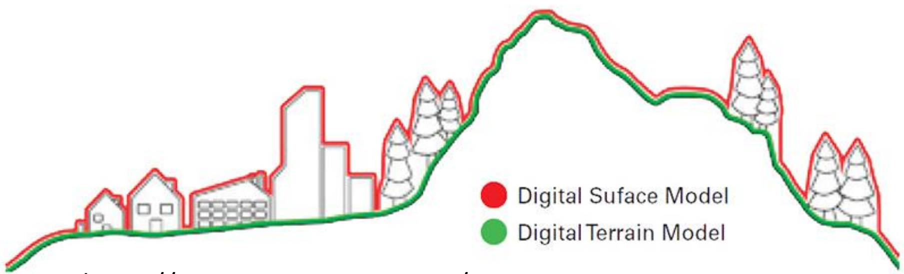


Fig. 2. Hill: (a) Definitions of parameters; and (b) dimensionless velocity speed-up ratios on top of hill. (Bradley 1980; Pearse et al. 1981)

A importância do modelo de elevação e da resolução espacial

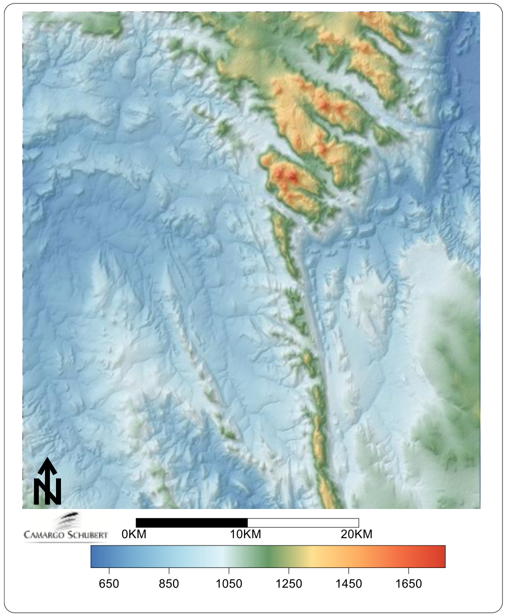


http://www.charim.net/datamanagement/32

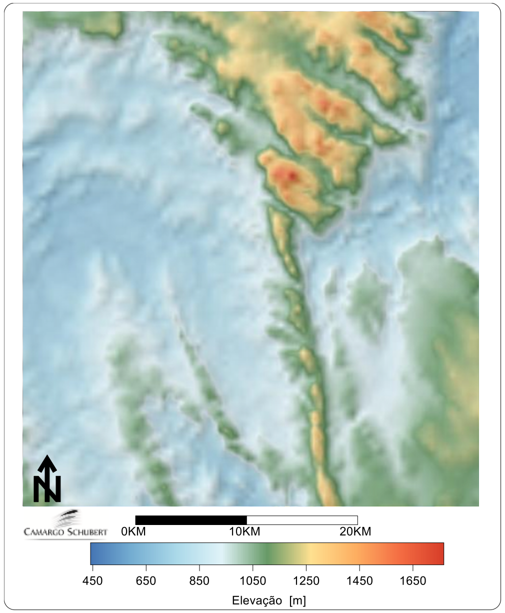


https://www.geoimage.com.au/

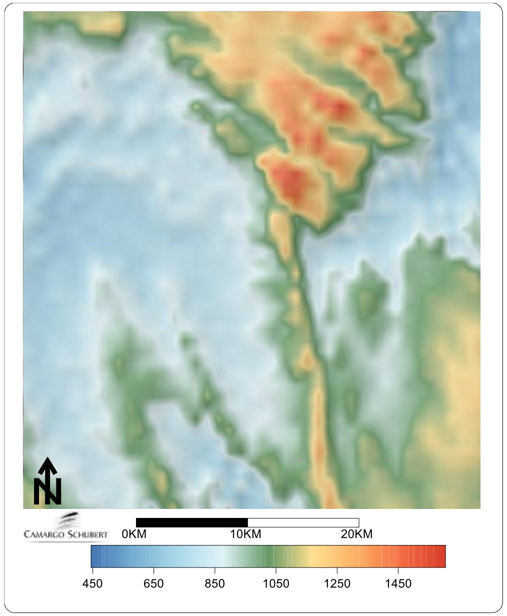
50metros



500 metros



1000 metros



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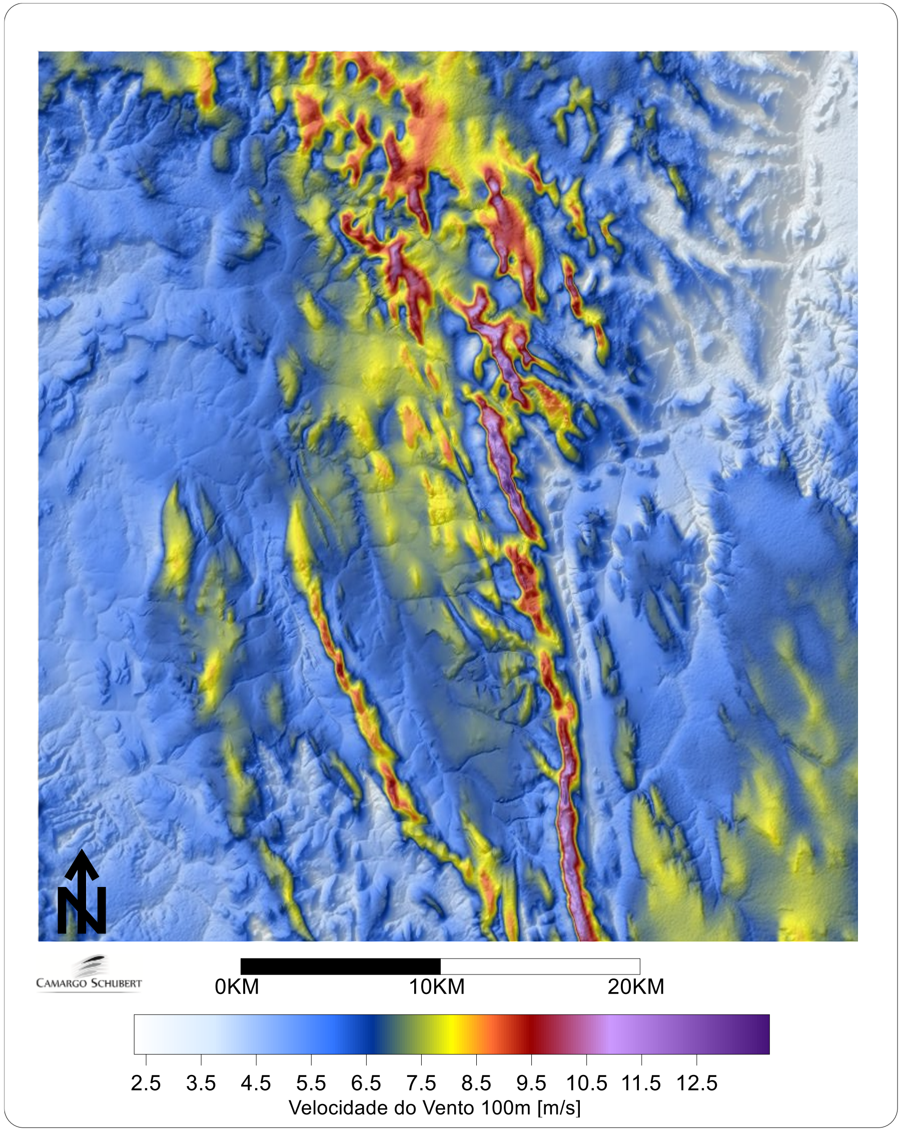
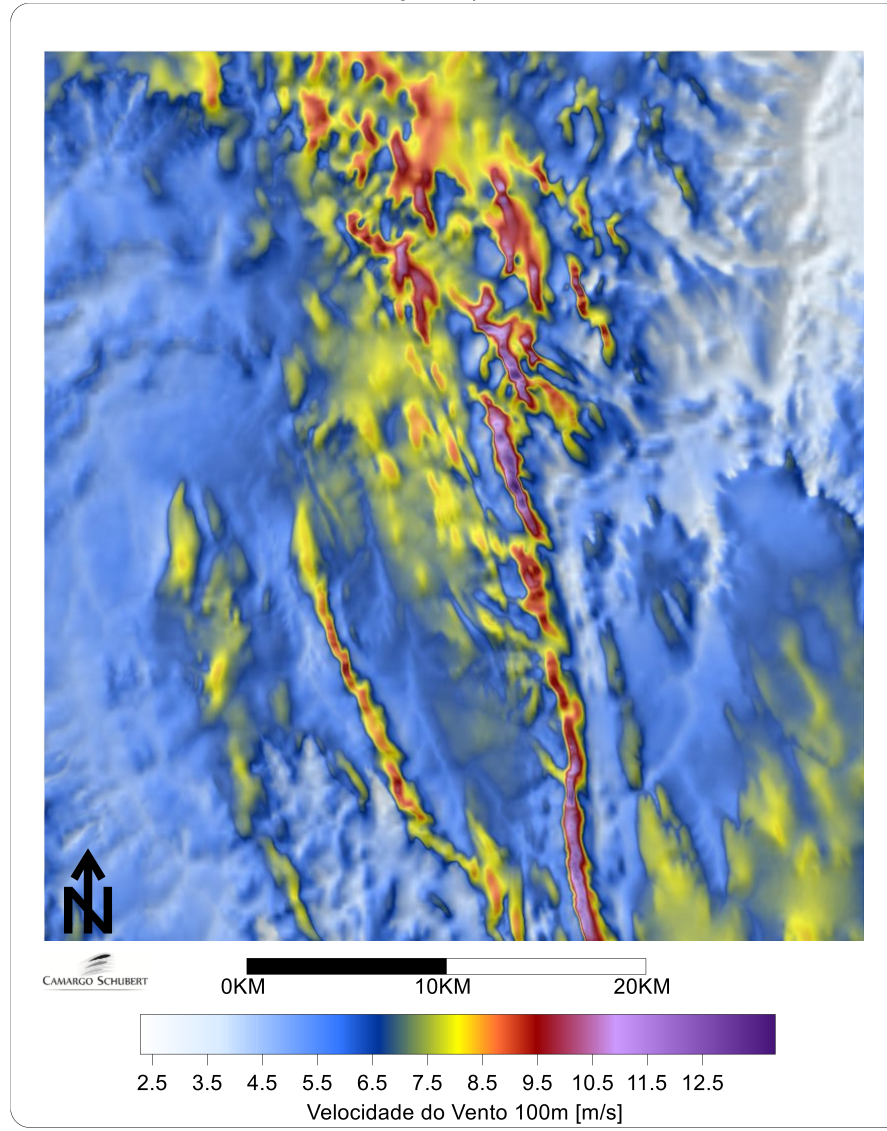
A importância do modelo de elevação e da resolução espacial

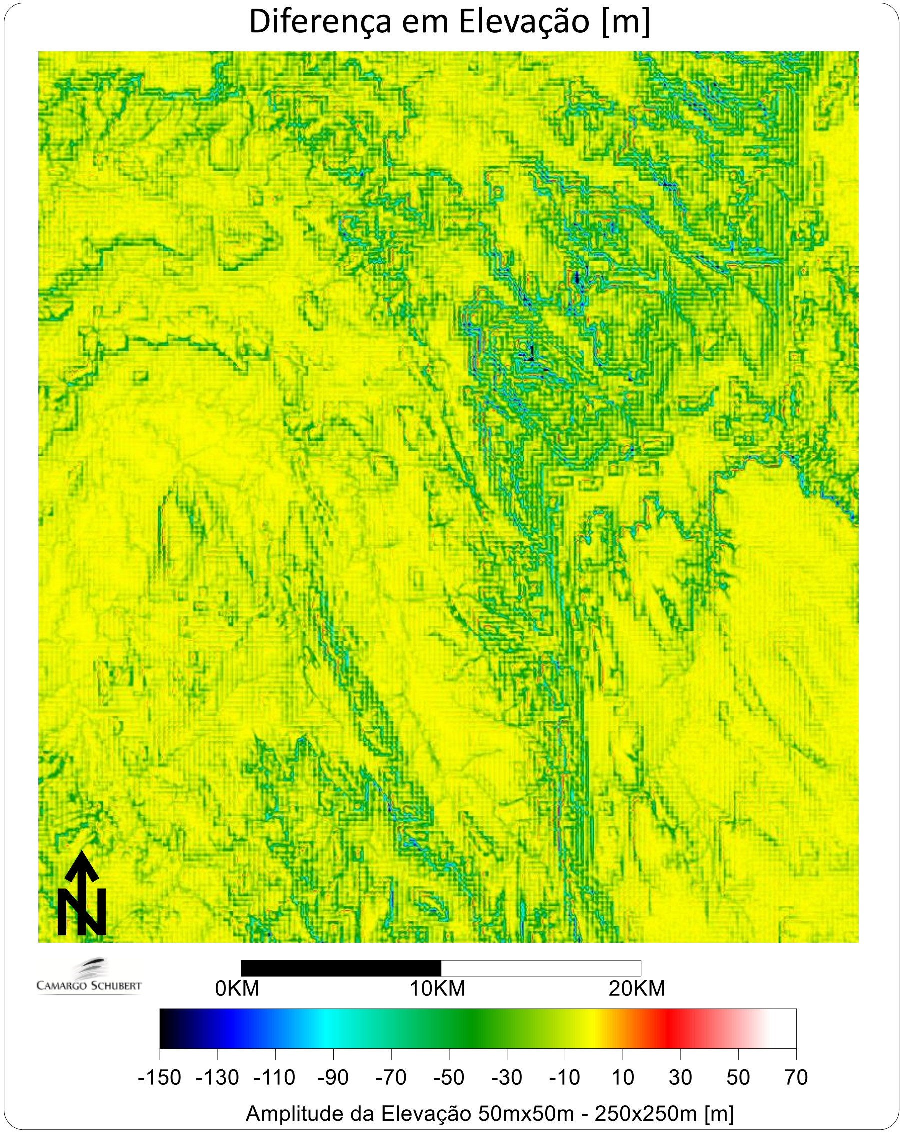
Resolução Espacial 50x50m

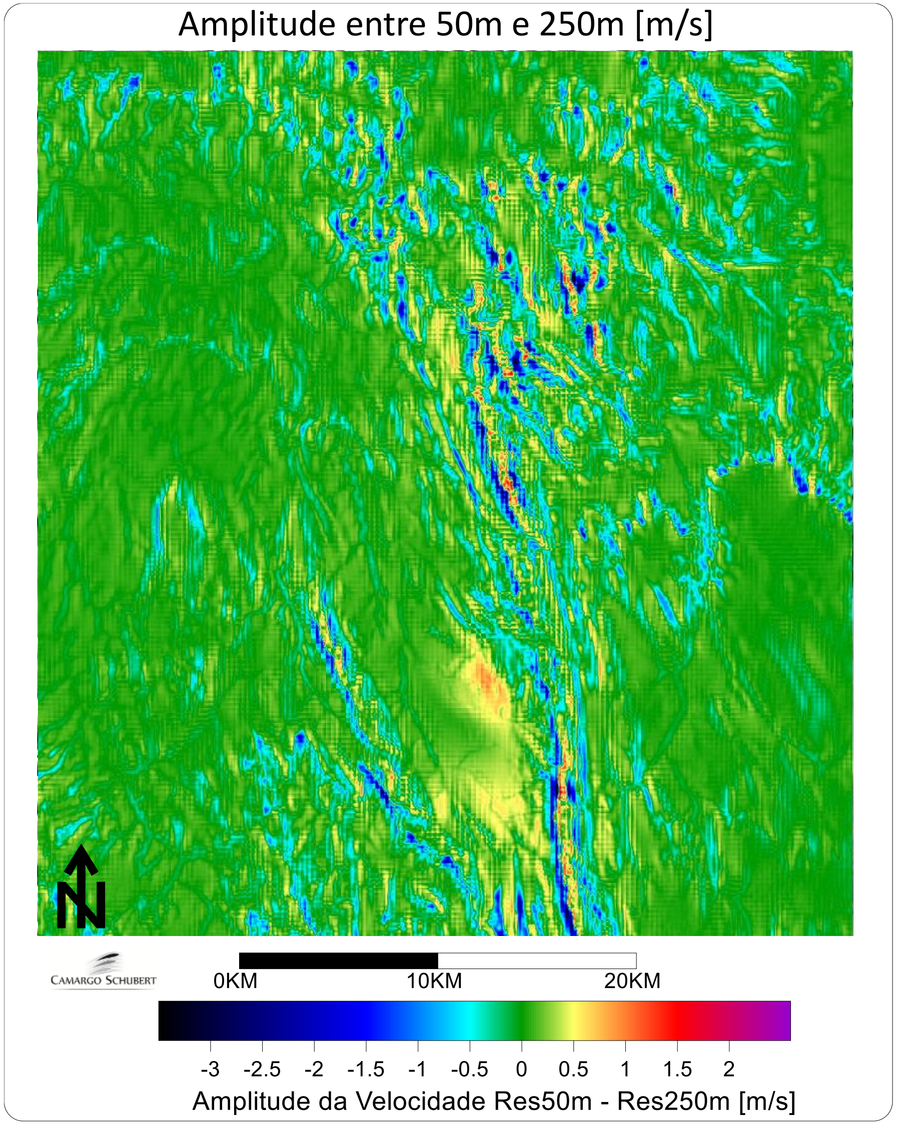


Resolução Espacial 250x250m

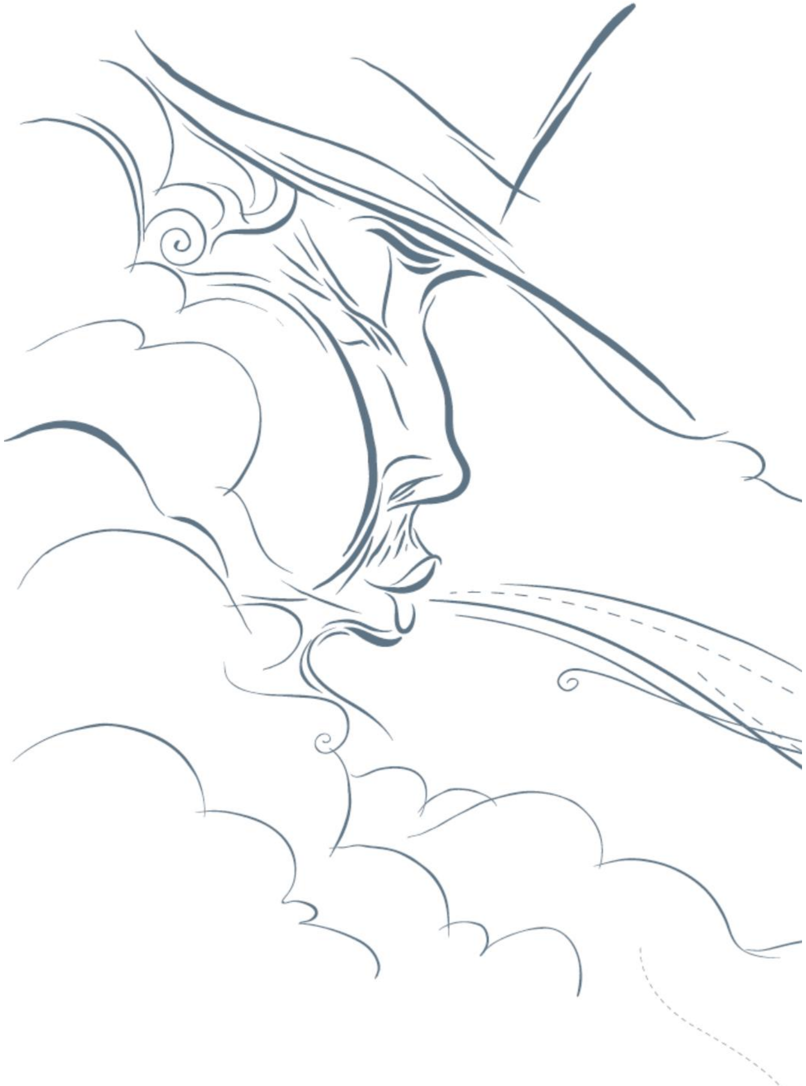


Diferenças entre resolução espacial





Considerações Finais



- A evolução da modelagem numérica e sua validação é fundamental para avaliação dos recursos eólicos.
- **Seguir procedimentos de validação e análise de incertezas da modelagem numérica garante sua credibilidade.**
- Regionalização de modelos e parâmetros pode ser um caminho para mesoescala ?
- **Necessidade de parâmetros e medições para aferição da PBL-SL (micrometeorologia + instrumentação)**
- **Pequenas variações na rugosidade aerodinâmica podem ter implicações diretas em projetos eólicos ou na previsibilidade (esteiras).**
- **A resolução espacial do modelo implica diretamente nos objetivos da modelagem e no tipo de topografia.**
- A inserção da estabilidade é um importante parâmetro na avaliação dos recursos eólicos.
- **A importância da interação com a comunidade de micrometeorologia e assimilação de dados**
- Modelagem numérica é fundamental na análise e quantificação da esteira de turbulência e perdas aerodinâmicas dos parques.
- **Necessidade de interação entre academia e empresas.**

Muito Obrigado !!!

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