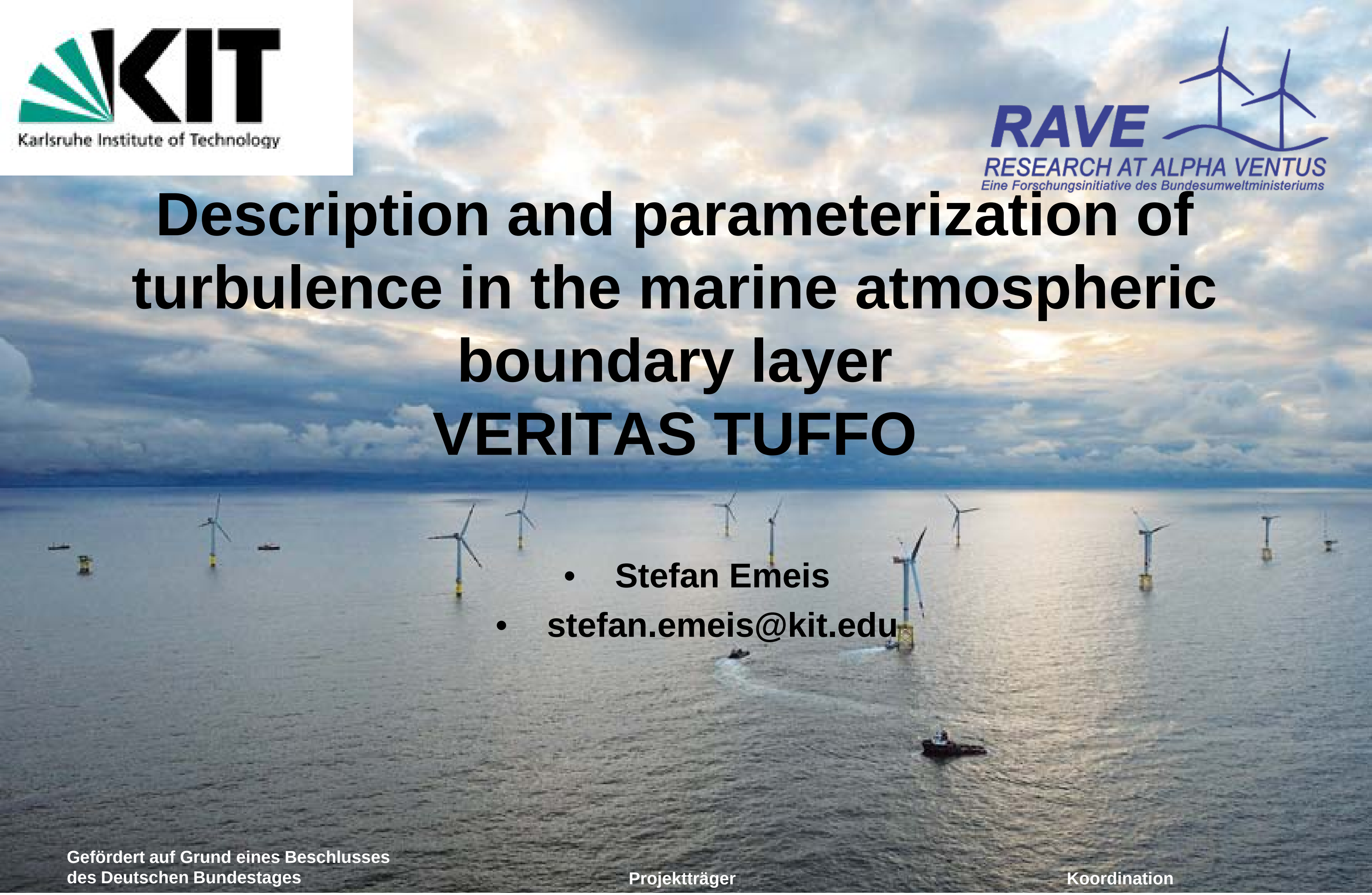

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RESEARCH AT ALPHA VENTUS
Eine Forschungsinitiative des Bundesumweltministeriums

Description and parameterization of turbulence in the marine atmospheric boundary layer
VERITAS TUFFO

- Stefan Emeis
- stefan.emeis@kit.edu

Gefördert auf Grund eines Beschlusses des Deutschen Bundestages

Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit

Projektträger

Projektträger Jülich
Forschungszentrum Jülich

Koordination

Fraunhofer IWES

WindForS Wind Energy Research Alliance

KIT Karlsruhe Institute of Technology

Meteorological challenges for offshore wind parks:

- marine atmospheric boundary layer is different:

- **- shallow atmospheric boundary layer**
- **- wind speed-dependent roughness and turbulence**
- **- wind direction and season-dependent atmospheric stability and turbulence**
- **- stability-independent vertical gradient of atmospheric humidity**

- necessity for reliable wind field models with correct description/parameterization of turbulence

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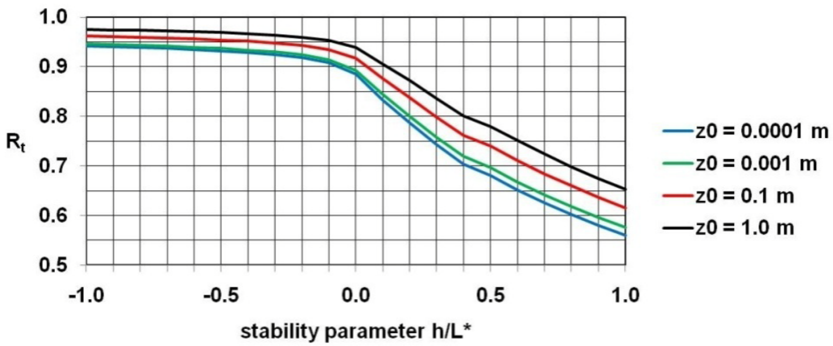
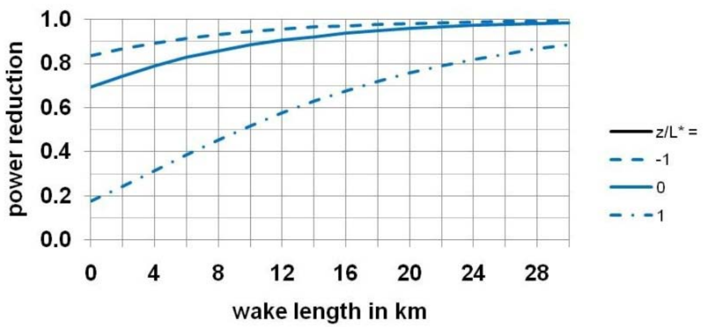
Turbulence

- influences loads on wind turbines (negative)
- influences harvests from wind turbines (positive)
- influences wind park efficiency (positive)
- influences wake lengths behind turbines and wind parks (positive)

power yield from large wind parks



available power behind large wind parks



🡐 more turbulence less turbulence 🡒

Emeis, S., 2010: A simple analytical wind park model considering atmospheric stability. Wind Energy, **13**, 459-469.

WindForS
Wind Energy
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VERITAS results

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VERITAS (July 1, 2008 to December 31, 2011)

Verification of **t**urbulence parameterization and description of the vertical structure of the maritime **a**tmospheric boundary layer in numerical **s**imulation models for wind analysis and forecast

became work package 5 of OWEA (see sessions 3 and 5 this morning)

investigators:

Richard Foreman M. Sc. (his PhD work, successfully completed Nov 31, 2011)
Prof. Dr. Stefan Emeis

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drag coefficient (neutral thermal stratification)

usual approach:

$C_{Dn} = u_*^2 / U^2$ (friction velocity over 10 m wind speed)

$= \kappa^2 / \ln^2(z/z_0)$ (over land: logarithmic profile)

☺ C_{Dn} is function of surface properties only

$= \kappa^2 / \ln^2(gz/\alpha u_*^2)$ (over sea: Charnock's relation)

💣 C_{Dn} depends on wind speed as well

empirically:

$C_{D10n} = 0.000063\ U_{10} + 0.00061$ (Smith 1980)

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VERITAS result #1

no wave data available:

within the fully turbulent regime:

friction velocity:

$u_* = 0.051\ U_{10} - 0.14$

input to the definition of C_D:

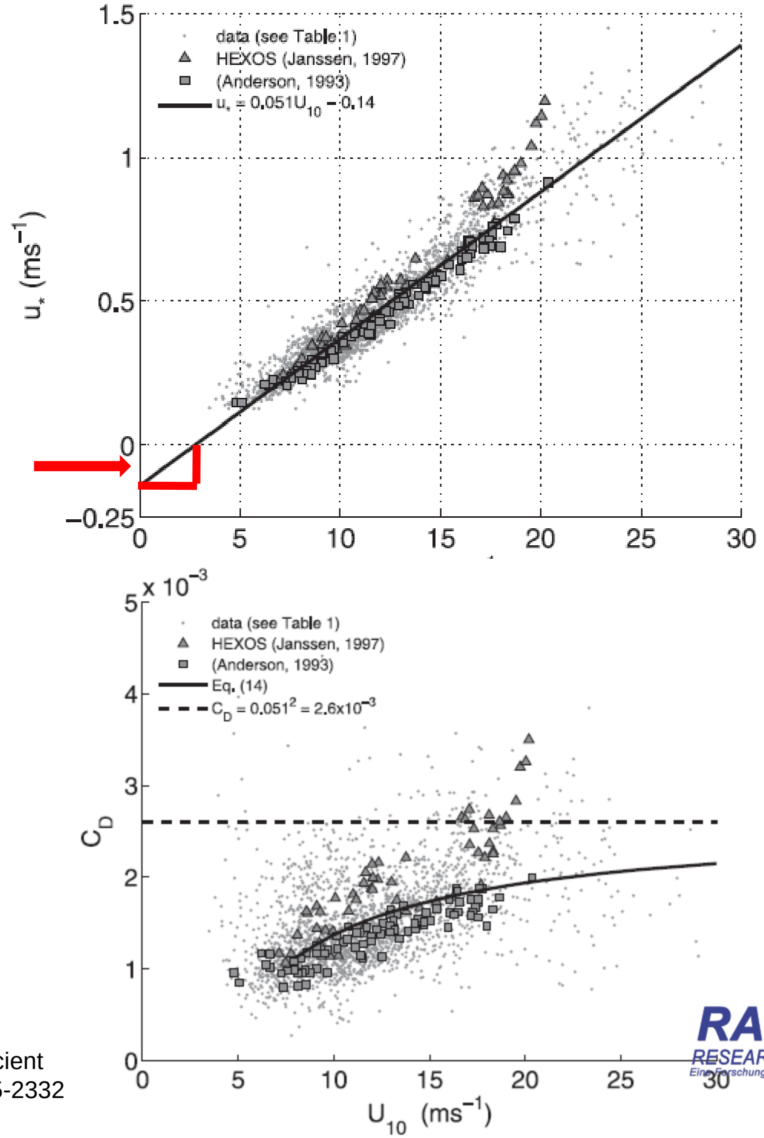
$C_{D10n} = (0.051\ U_{10} - 0.14)^2 / U_{10}^2$

$C_{D10n} = (C_m\ U_{10} - b)^2 / U_{10}^2$

approaches:

$C_m^2 = 0.051^2 = 0.0026$

for large U_{10}

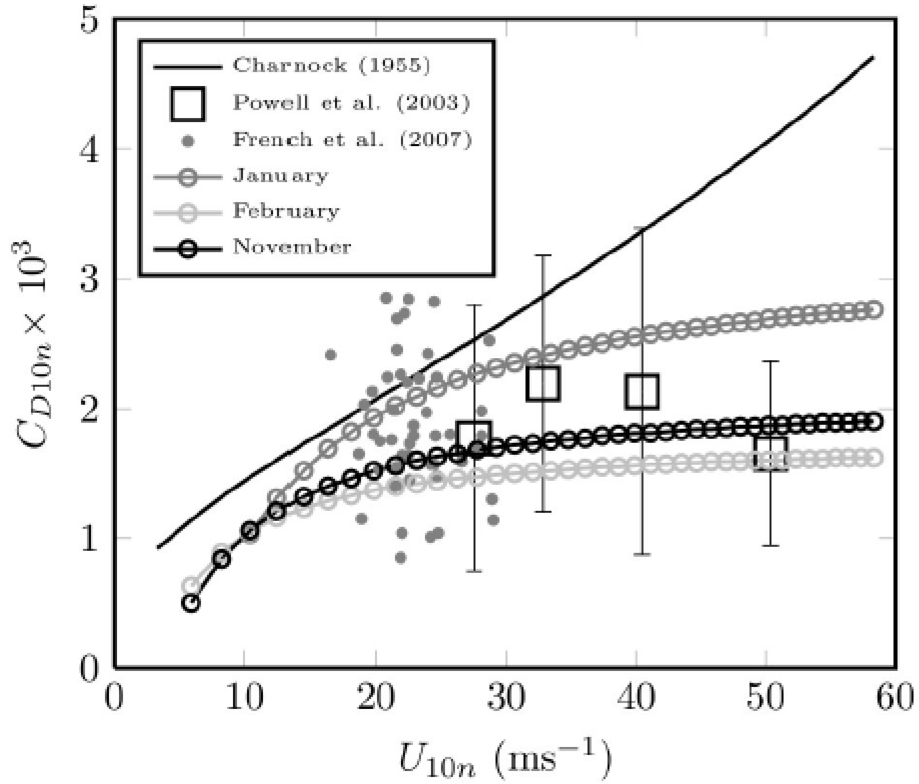


Foreman, R., S. Emeis, 2010: Revisiting the Definition of the Drag Coefficient in the Marine Atmospheric Boundary Layer. J. Phys. Oceanogr., **40**, 2325-2332

VERITAS result #1

Comparison with data:

	C_m	b
Literatur	0.051	0.14 m/s
FINO Jan 2005	0.057	0.26 m/s
FINO Feb 2005	0.042	0.01 m/s
FINO Nov 2005	0.048	0.02 m/s



- C_{D10n} still depends on wind speed (but at least: C_m does not)
  the plot shows a non-dimensional variable plotted against a dimensional one

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VERITAS result #2

wave data available:

$C_{D10n} = a\,(H_s/\lambda_p)^2$ (from dimensional analysis)

the drag coefficient should not approach zero for vanishing waves. Therefore a minimum is set:

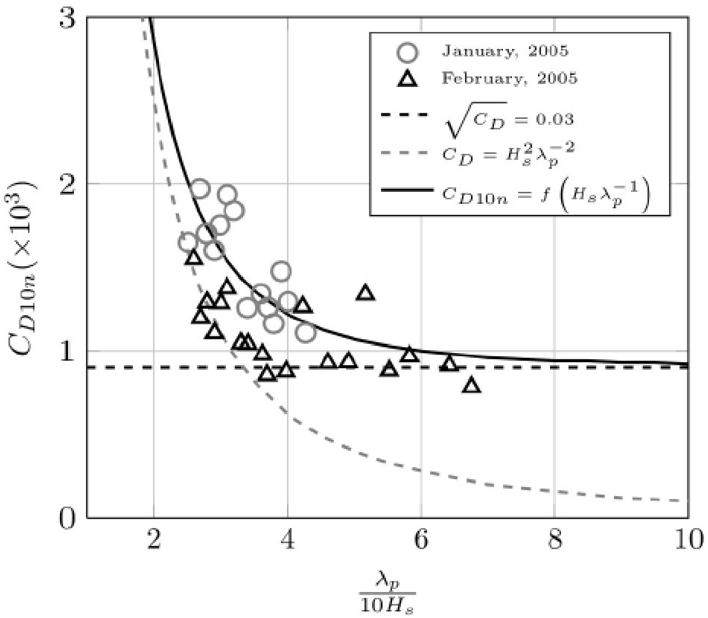
$C_{D10n} = 0.0009$ (smooth surface)

fit between both extremes:

$(C^{1/2}_{D10n})^n = 0.03^n + (H_s/\lambda_p)^n$

empirically $n \approx 3$

(Churchill and Usagi 1972)



steep ← → shallow

☺ C_{D10n} depends on surface parameter only
☺ both axes in plot are now non-dimensional

VERITAS result #3

turbulence parameterization in meso-scale wind field models such as MM5 or WRF:

	A1	A2	B1	B2	C1
MY 1982	**0.92**	**0.74**	**16.6**	**10.1**	**0.08**
MYJ 2002	**0.660**	**0.657**	**11.878**	**7.227**	**0.00083**
new	**0.91**	**0.54**	**28.76**	**13.08**	**0.15**

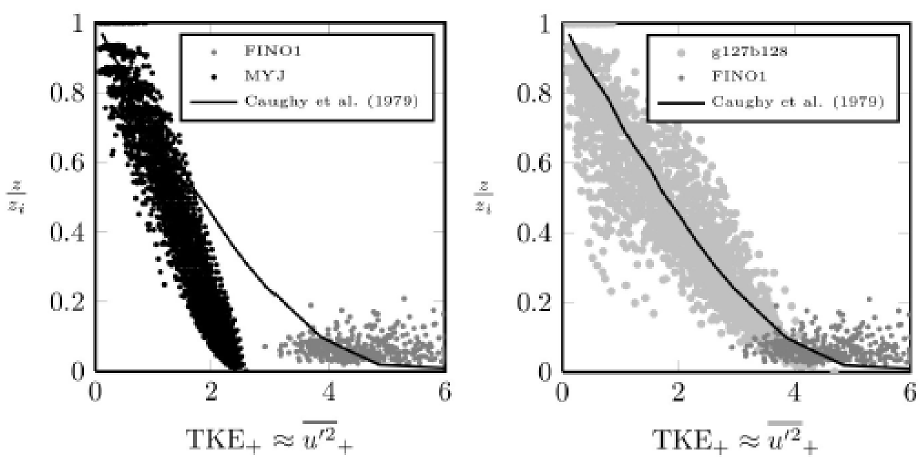
plus an adaptation of turbulent length scales following Nakanishi (2001)

new values are based on modern laboratory data
- at very high Reynolds numbers
- with very small velocity sensors close to the wall

Foreman, R., S. Emeis, 2012: Method for increasing Turbulent Kinetic Energy in the Mellor-Yamada-Janjić boundary layer parametrization. accepted by Bound.-Lay. Meteorol.

VERITAS result #3

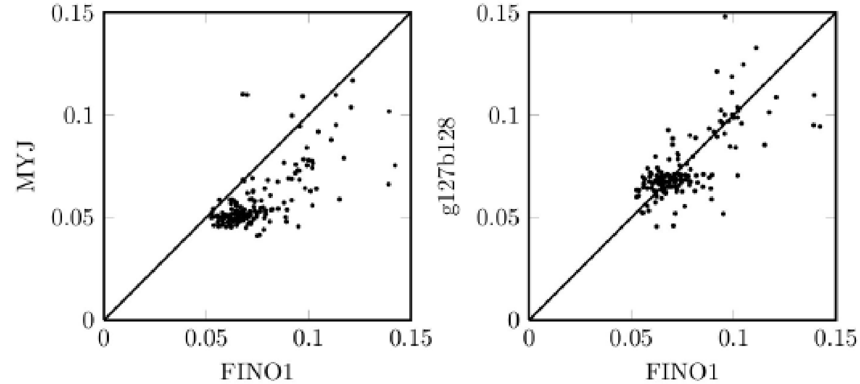
comparison of model results with offshore (FINO1) and onshore (Caughey et al. 1979) data



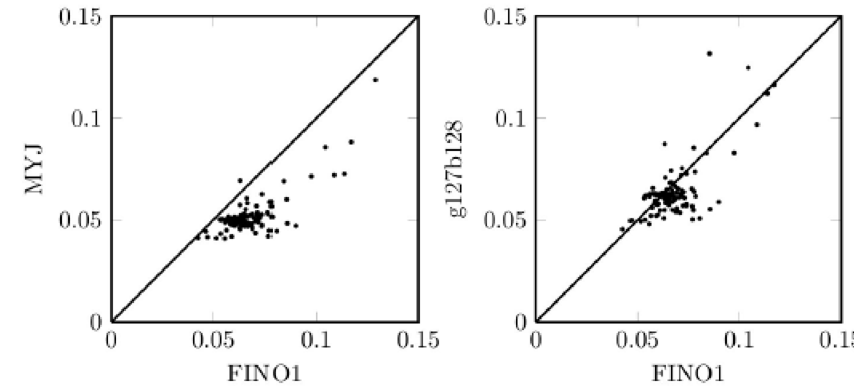
old **new**

vertical profiles of normalised turb. kin. energy January 2005

turbulence intensity at 80 m height February 2005



old **new**



turbulence intensity at 80 m height November 2005

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TUFFO idea

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Institute for Meteorology and Climate Research –
Atmospheric Environmental Research

WindForS Wind Energy Research Alliance

KIT Karlsruhe Institute of Technology

TUFFO (August 1, 2011 to July 31, 2014)

Detection and assessment of the impact of **tu**rbulent humidity (**F**euchte) **f**luxes on turbulence in **o**ffshore wind parks

investigators:

Dr. Richard Foreman
Prof. Dr. Stefan Emeis

Institute for Meteorology and Climate Research
Dept. of Atmospheric Environmental Research
Karlsruhe Institute of Technology
Garmisch-Partenkirchen. Germany

Dr. Beatriz Cañadillas
Dr. Thomas Neumann

German Wind Energy Institute (DEWI)
Wilhelmshaven, Germany

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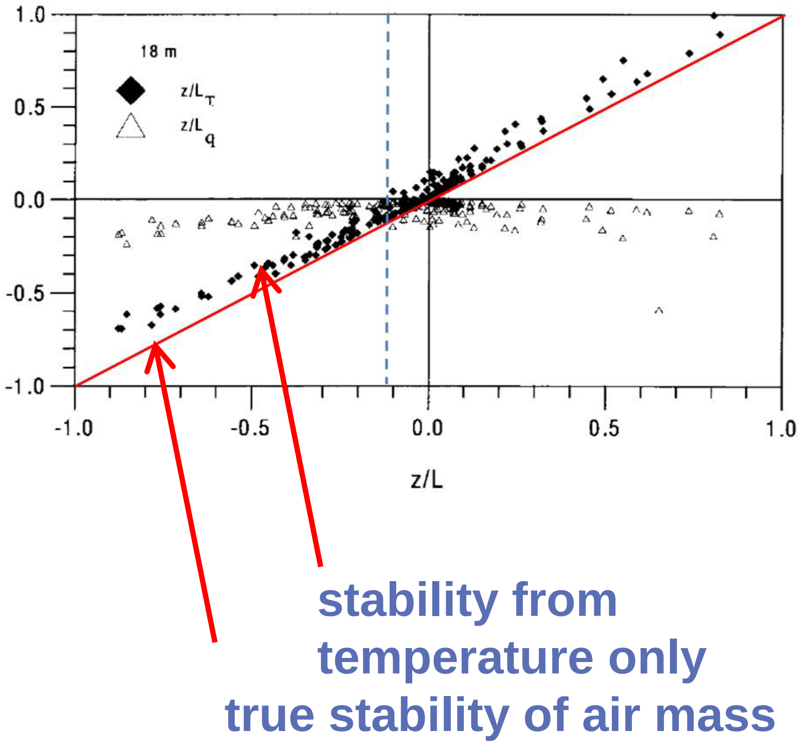
TUFFO idea

humid air is lighter than dry air

sea surface is a perfect humidity source

- ➔ **near surface air is nearly saturated**
- ➔ **air aloft is less saturated**

- ➔ **less static stability (in 30 to 50 % of all cases: humidity profile decides on static stability**
  (Sempreviva and Gryning 1996, Edson et al. 2004)



- ➔ **more turbulence**

- ➔ **more loads on turbines**
- ➔ **less wake lengths behind turbines and wind parks**

TUFFO idea

<u>new approach in TUFFO:</u>

deployment of high-speed humidity sensors to FINO 1 co-located with ultra-sonic anemometers

➔ high-resolution humidity data
➔ turbulent vertical humidity fluxes
➔ better static stability information

assessment of impact on turbulence at hub height

assessment of impact on wind parks (efficiency, wake lengths)

update of turbulence parameterization in meso-scale wind field models

Summary:

VERITAS

<u>sea surface drag description</u>

no wave data: sea surface drag flattens off for high wind speeds

with wave data: sea surface drag depends on wave steepness squared

<u>meso-scale wind field models</u>

enhanced turbulence parameterization which gives higher (more realistic) turbulence intensities in the lower part of the atmospheric boundary layer

TUFFO

<u>vertical humidity structure in the marine boundary layer</u>

leads to more unstable static stratification ➔ more turbulence

Thank you very much for your attention

Gefördert auf Grund eines Beschlusses des Deutschen Bundestages

Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit

Projektträger

Projektträger Jülich Forschungszentrum Jülich

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