Enhancing the prediction of turbulent kinetic energy in the marine atmospheric boundary layer

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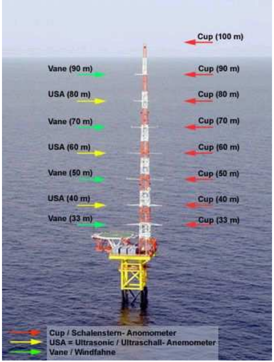
Overview

- Our work focuses on improving the calculation of turbulent quantities, e.g. turbulent kinetic energy (TKE), over water surfaces by numerical weather prediction models.
- We will show model updates that improve the calculation of TKE over water
    - Also valid over land.
- Enhancement of knowledge of offshore turbulence associated with the growth of offshore wind energy.

FINO1 - Offshore research platform



- FINO1 - North Sea, 45 km North of Borkum Island.
- Cup anemometers 30-100 m every 10 m.
- Sonic anemometers 40, 60 & 80 m.

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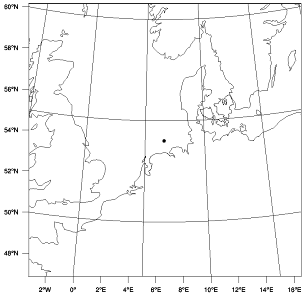
Initial Model Results - WRF (Weather Research and Forecasting) model setup



- Use Weather Research and Forecast (WRF) model (http://www.mmm.ucar.edu/wrf/users/)
- Planetary boundary layer scheme: Mellor-Yamada-Janjic (MYJ)
  - Differential equation for TKE: $\frac{1}{2}q^2 = \frac{1}{2}\left(\overline{u'^2} + \overline{v'^2} + \overline{w'^2}\right)$
  - Exchange coefficients solved algebraically.
  - These outputs will be shown below.
- Single domain: 151 x 151 x 10 km resolution, 51 model levels

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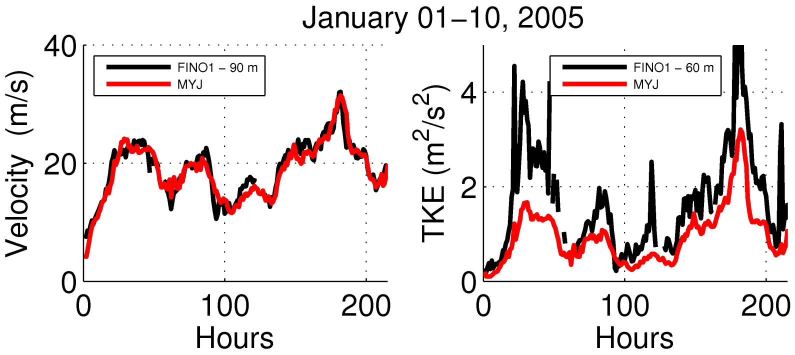
Initial Model Results - FINO 1



- January 01-10, 2005 - High wind speeds, steady wind direction (Westerly).
- Wind speed captured well.
- Turbulent kinetic energy underpredicted.

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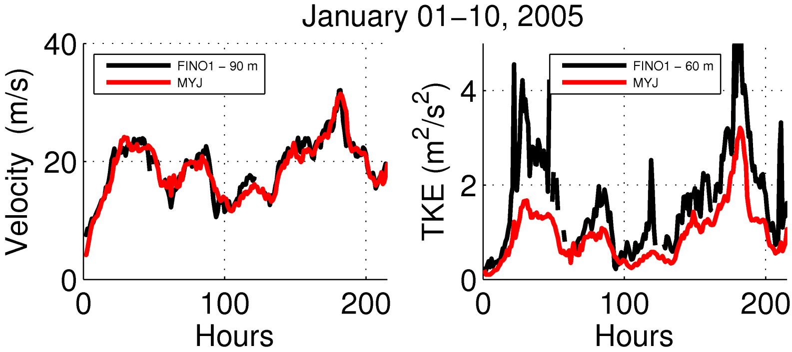
Initial Model Results

- Investigate reasons for the underprediction of TKE.
- Could turbulence be higher at FINO 1 due to the presence of waves?
- But experimental and field data is as yet inconclusive.
- Considerable variance in particularly field results.
  - Some suggesting higher turbulence over water compared with land (and vice versa).

Why then is the turbulence at FINO1 so poorly predicted?

- Difficult to distinguish a clear difference between the magnitude of turbulence over water and land with currently available data



Recent experimental boundary layer data

- MY closure constants determined from laboratory data between 1950-1975.
- Closure constants determined from turbulent statistics in range where production = dissipation and Reynolds number independence (close to the wall).
- Have measurement techniques advanced sufficiently since then?
- In MY model, closure constant $B_1 = \left(\frac{q}{u_*}\right)^3$.
- MY82: $\frac{q}{u_*} = 2.55$ ($B_1 = 16.58$)
- Current WRF model: $\frac{q}{u_*} = 2.28$ ($B_1 = 11.85$)
- More recent data suggests this should be higher:

Recalibrated MYJ scheme in WRF - FINO1

Table: Summary of statistics from recent high Reynolds number boundary layer experiments.

Author	Re (x 10^4)	$\frac{u'}{u_*}$	$\frac{v'}{u_*}$	$\frac{w'}{u_*}$	$\frac{q}{u_*}$	$B_1 = \left(\frac{q}{u_*}\right)^3$
Österland (1999)	2.25	2.3	1.55	1.05	2.97	26.2
Carlier & Stanislas (2005)	2.06	2.31	1.52	1.06	2.96	25.9
<u>Mellor-Yamada Models:</u>						
Mellor & Yamada (1982)	-	1.9	1.2	1.2	2.55	16.6
Current WRF	-	1.70	1.07	1.07	2.28	11.9
Updated here	-	1.97	1.57	1.57	2.96	26.0

- Update MYJ coefficients based on $B_1 = 26.0$ (see Mellor & Yamada, 1982)
- Modify master length scale based on Nakanishi (2001).
- Obtain dimensionless wind and temperature gradients matching Businger (1971).

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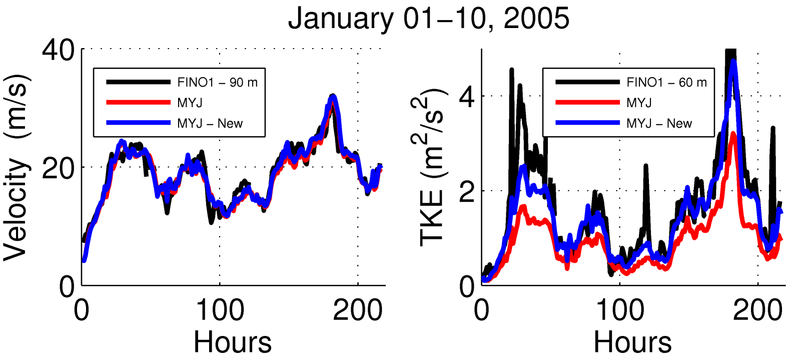
Results - FINO1



- Mean velocity essentially unchanged (slightly higher).
- Turbulent kinetic energy improved by roughly 40% (RMS)

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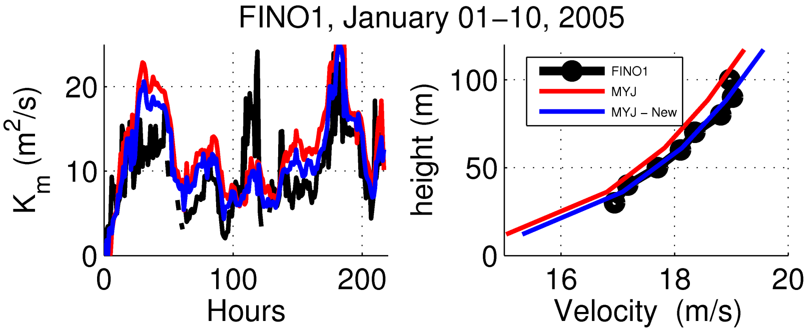
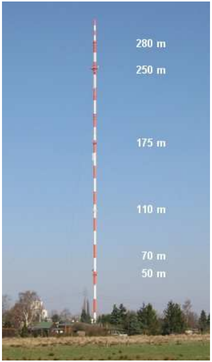
Results - FINO1



- K_m reduced and improved by roughly 20%
- Higher velocity shear.

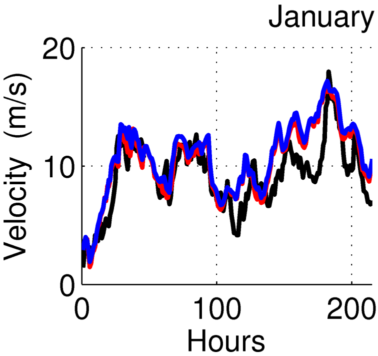
Results over land - Hamburg Weather Mast

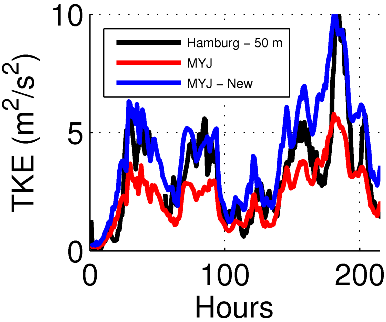


- Hamburg Weather Mast.
- Data here from cup and sonic at 50 m.

Recalibrated MYJ scheme in WRF
- Hamburg weather mast -

- Test to see if constants work over land





Some conclusions and currently ongoing work

- Updates to the MYJ boundary-layer model improve calculation of turbulent quantities both over land and sea.
- Further conditions are being tested at FINO1 (different atmospheric stabilities).
- Much more testing needed over land.
- Looking for things specific over water to be included in the WRF model (coupling of WRF with a wave model?).

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