Current research and plans based on BLLAST dataset

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Outline

- OffWind project.
- BLLAST dataset.
- OpenFOAM solver.

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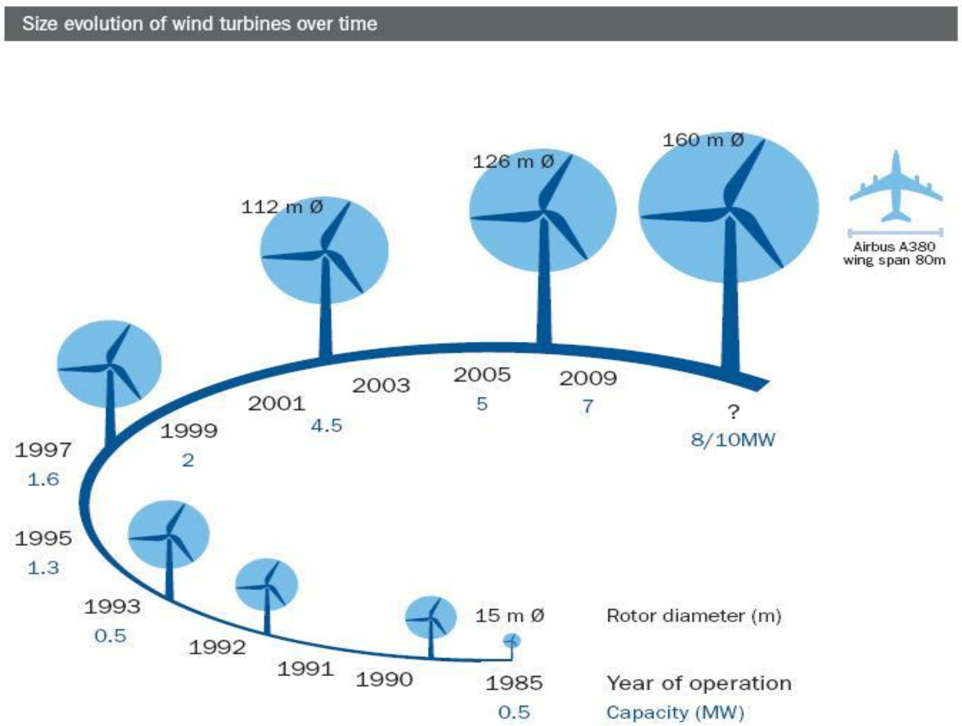
OffWind

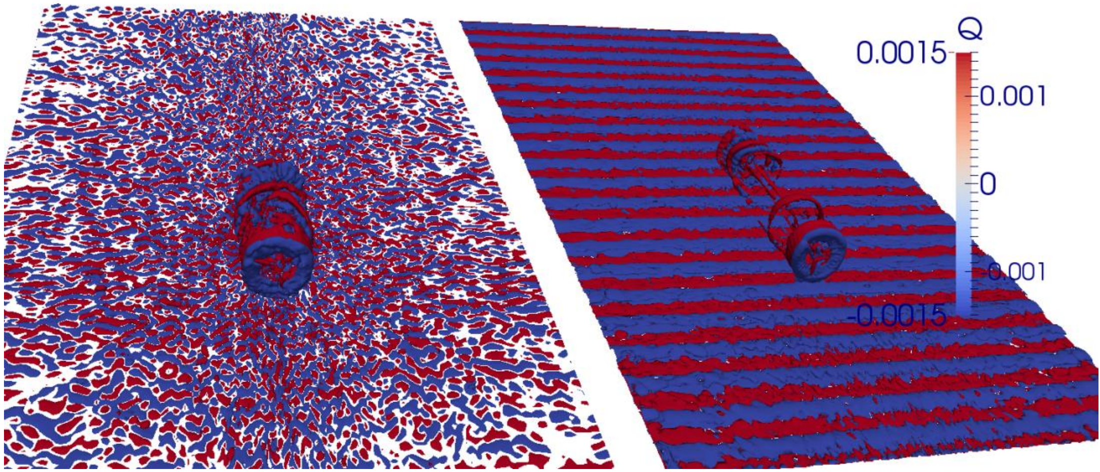
- Offshore wind energy
  - Wind-Wave interactions.
  - Diurnal variation of ABL.
  - Roughness and thermal discontinuity.
- ABL
  - Lower part of the ABL.
  - Wind velocity.
  - Wind shear and veer.
  - ABL turbulent intensity.
  - Surface forcing.



Bernhard Lange/University of Oldenburg, Oldenburg, Germany
Søren Larsen/Risø National Laboratory, Roskilde, Denmark

OffWind

- Aproach
  - Low Re flow
  - High Re ABL



OffWind

- Method
  - Large Eddy Simulations
  - Open source computational fluid dynamic toolbox OpenFOAM 2.1.3
    - Collocated 2nd order implicit finite volume solver.
    - pseudo-staggered grid setup is used.
    - The pressure-momentum system is decoupled using the PIMPLE method (merged PISO-SIMPLE)
    - 16 different SGS models.

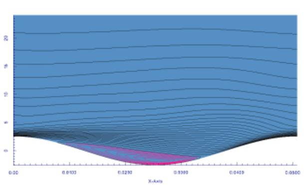
OffWind

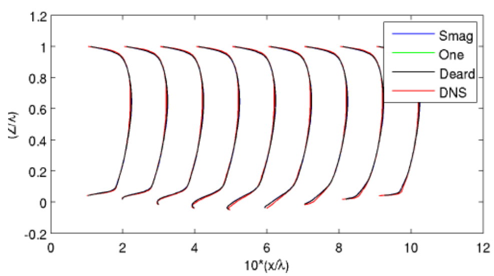
- Challenges
    - Realistic BCs
    - Mesh resolutions
    - Validations

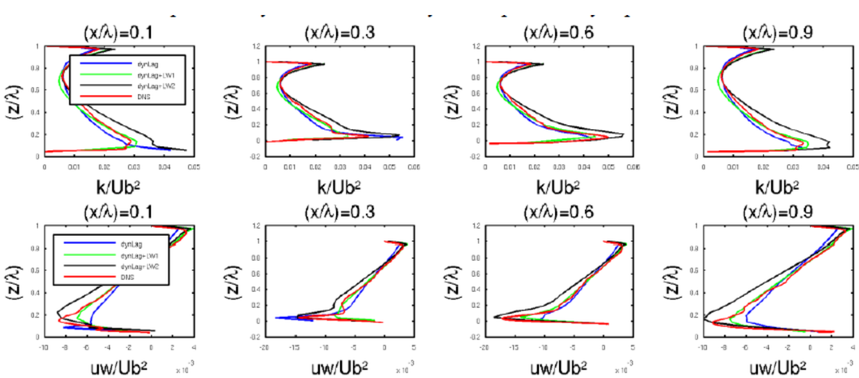
LUND UNIVERSITY

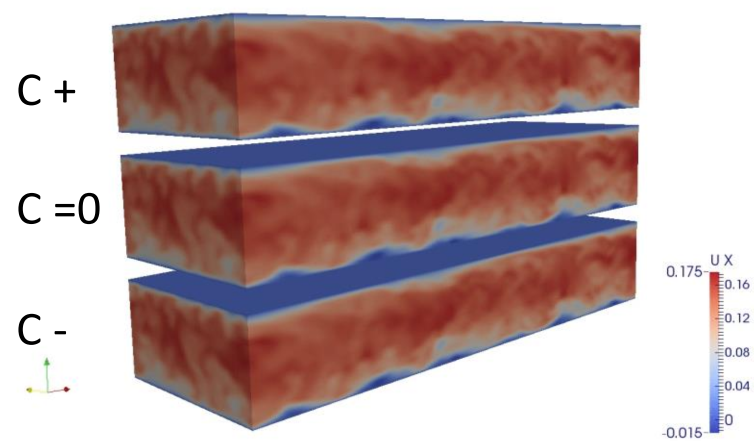
- Uniform fixed waves
  - Numerical setup
  - SGS and wall models
  - Wave effects

- Uniform moving waves
  - Wave age
  - Wave slope
  - Wave direction
  - Wave types





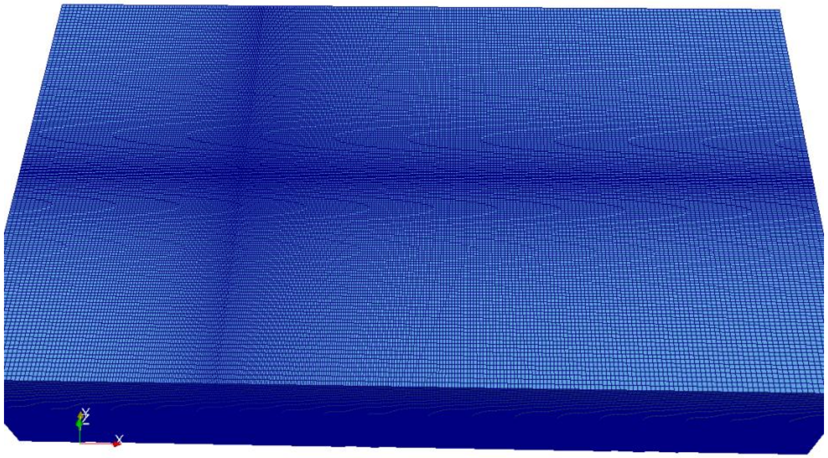




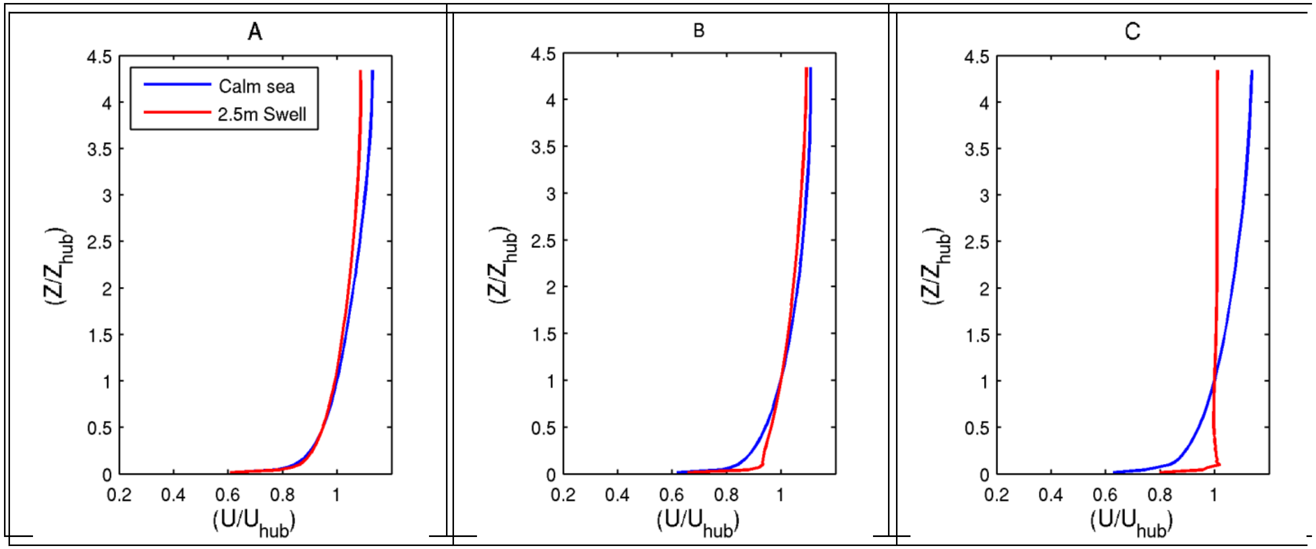
ABL Simulations

- ❑ ABL simulations to investigate
  - ❑ Wave effect on ABL
  - ❑ Wave to wind velocity ratio effects
  - ❑ Wave height to wave length effects
  - ❑ Validity of MO similarity theory

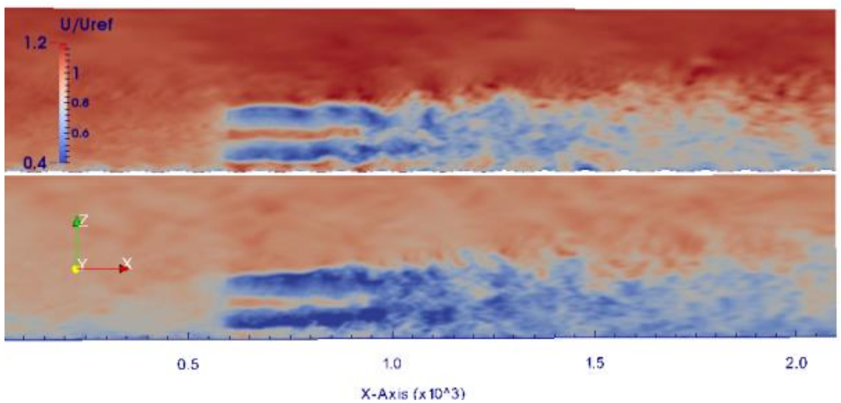
- ❑ ABL + WT simulations to investigate
  - ❑ WT power producation
  - ❑ WT wake strength
  - ❑ WT wake length

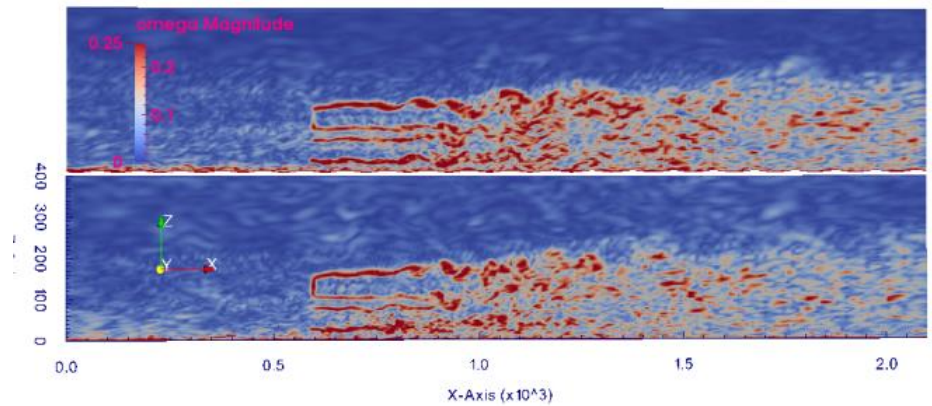


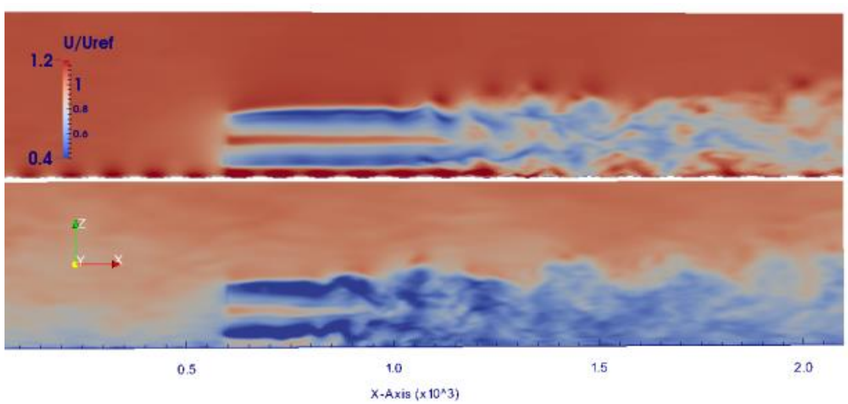
ABL simulations

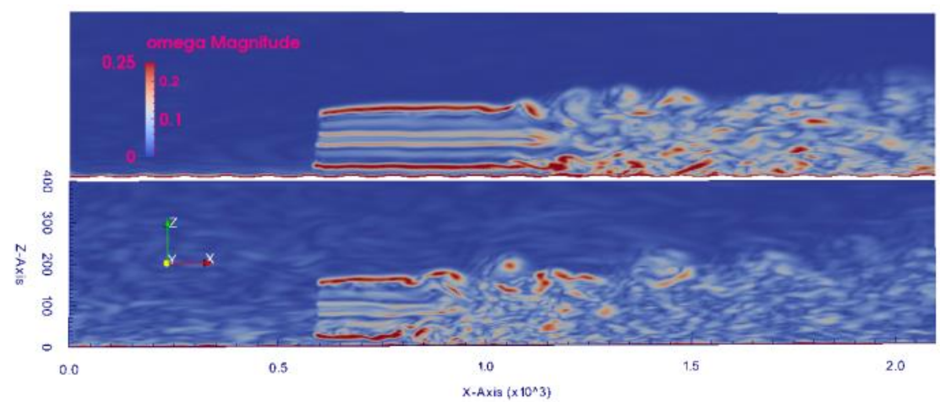


ABL simulations

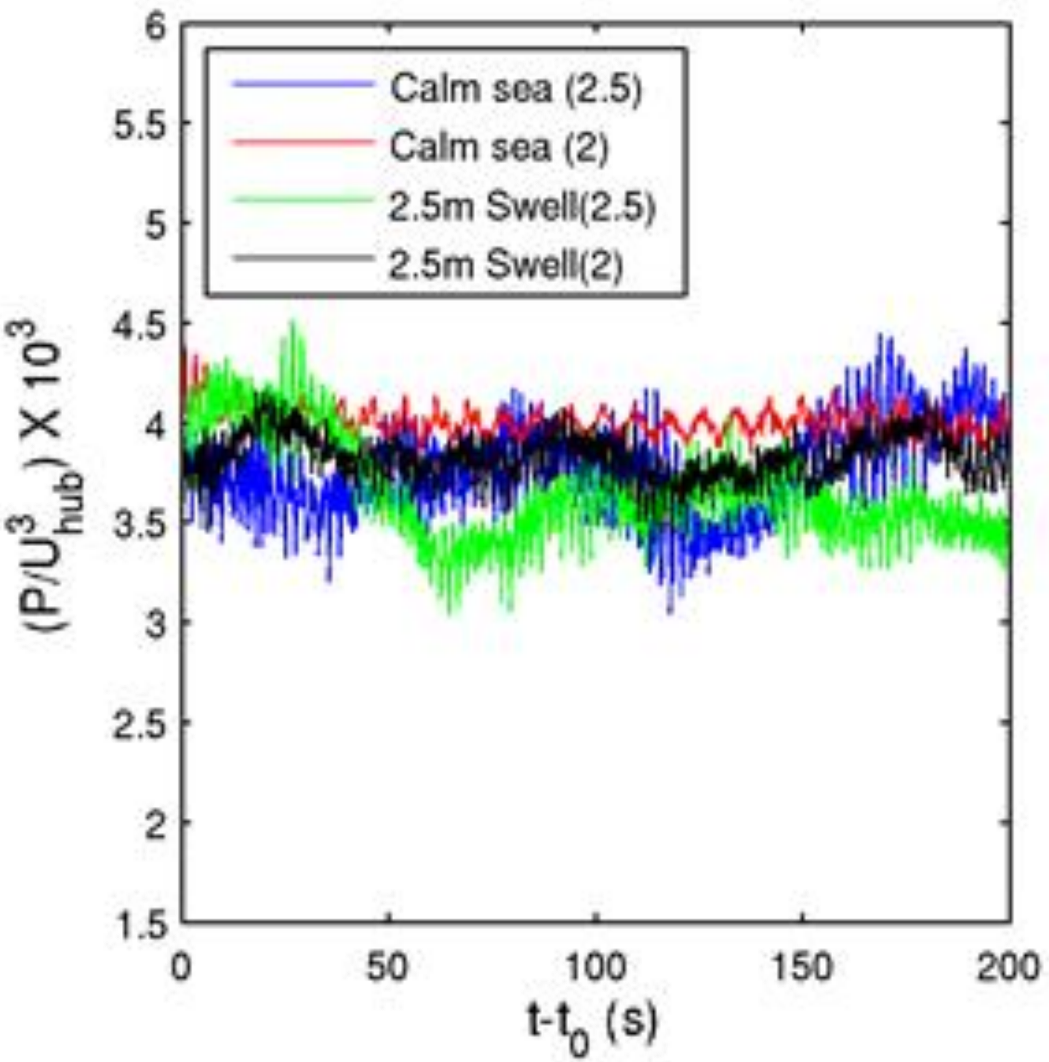








ABL simulations



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BLLAST Dataset

- ❑ Diurnal variation of ABL.
  - ❑ WT power producation variation.
  - ❑ WT wake, wake-wake interaction.
  - ❑ WT mechanical load.

Ex. The power output data from Horns Rev Offshore wind farm (given by Jensen 2007)

- ❑ Stable ABL the farm's efficiency is 61%
- ❑ unstable ABL the farm's efficiency is 74%

BLLAST Dataset

- LES of ABL with:
  - Observed near-surface fluxes.
  - Observed external forcing.

  - ABL characterstics
  - Wind velocity profile
  - TKE evolution.
- LES of ABL with Wind turbine(s):
  - Durinal power extraction variation.
  - ABL – WT's wake interaction.

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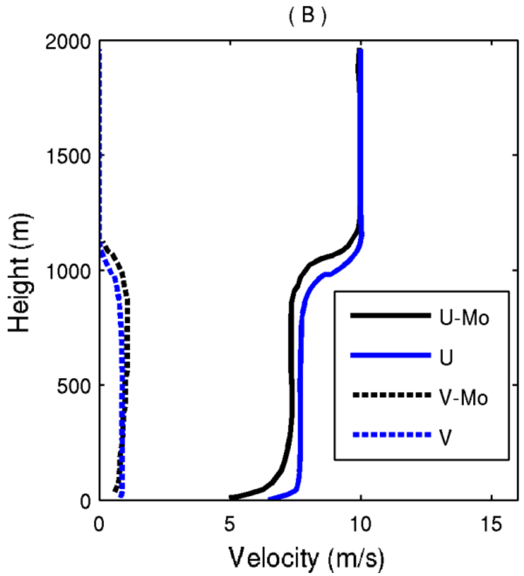
BLLAST Dataset

- Modifications:
  - Coriolis force.
  - External driving pressure force grdP:
    - Presecribed constant geostrophic wind Ug.
    - Ug=F (z).
    - Ug=F (t).
    - Fixed flow velocity of a plane at a certain height.
  - A divergence-free perturbation.
  - Equation for virtual potential temperature.
    - Boussinesq approximation.
    - The length scale $l = F(\Delta s)$, No stratification modification !
    - Constant Prt ($K_m/K_h=0.33$) No stratification modification !
    - pressure and buoyancy terms are treated implicitly in the momentum equation, while the Coriolis and the driving pressure force terms are treated explicitly .

BLLAST Dataset

- Modifications:
  - Surface stress models :
    - Schumann model: $\frac{\tau}{\langle\tau\rangle_w} = \frac{\bar{U}_{z1}}{\langle\bar{U}\rangle_{z1}}$.
      - Constant u_f and q_w .
      - $u_f(t)$, $q_w(t)$ From MO similarity t
        - Constant Z_0.
        - $Z_0 = F(x, y)$.



- (5 x 5 x 2)(km)
- (96 x 96 x 96) cells
- Ug=(10 0 0)(m/s)
- q_w=0.24b(mK/s)
- U_f=0.56 (m/s)

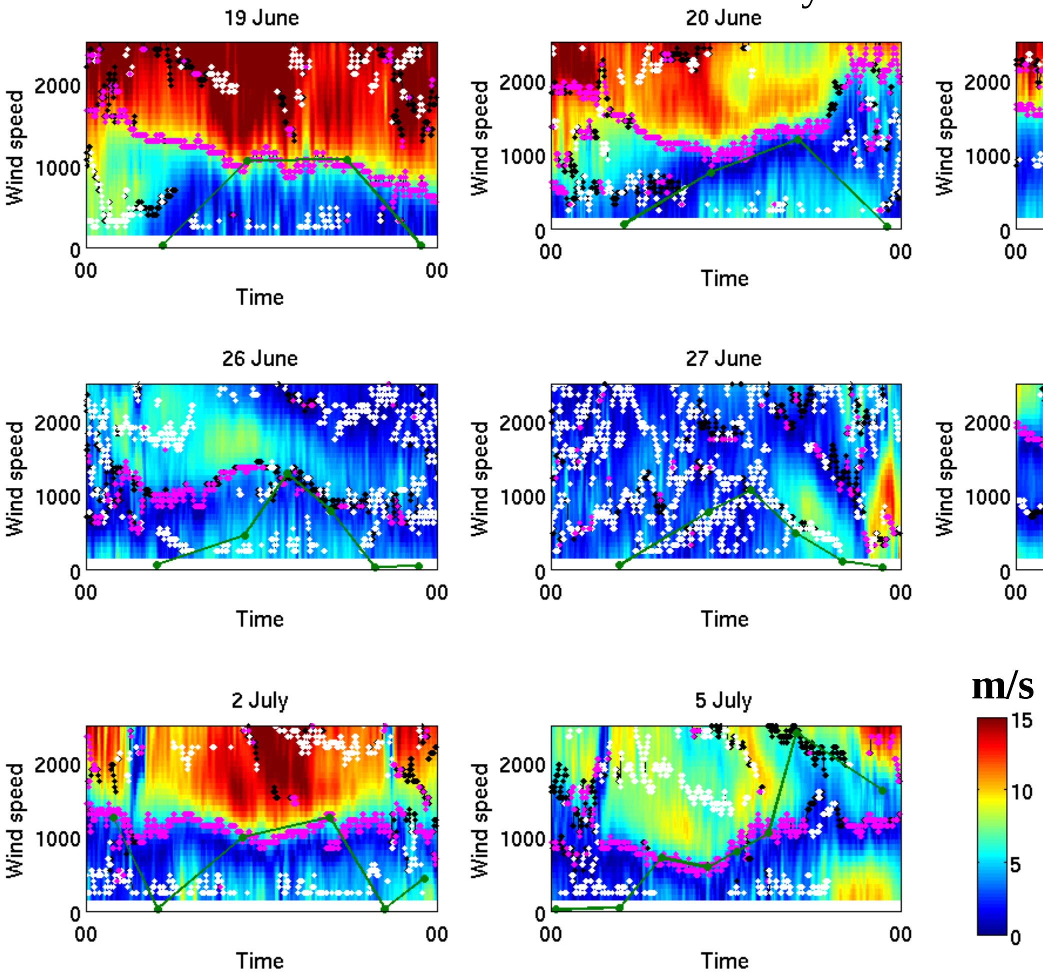
C. Moeng and P. Sullivan (1994)

BLLAST Dataset

- Modifications:
  - Surface stress models :
  - Moeng model $\frac{\tau}{\langle \tau \rangle_w} = \frac{S_{z1}\langle \overline{u} \rangle_{z1} + \langle S \rangle_{z1}(\overline{u}_{z1} - \langle \overline{u} \rangle_{z1})}{\langle S \rangle_{z1}\langle U \rangle_{z1}}$.
    - Constant u_f and q_w .
    - $u_f(t)$, $q_w(t)$ From MO similarity theory (Average, Local).
      - Constant Z_0.
      - $Z_0 = F(x, y)$.

Smoothed and gapfilled wind speed from UHF

By Erik Nilsson



Strong local maximas in wind gradient (more than 1 m/s change in 100 m) shown in purple.

Moderate in black and weak in white (<0.5 m/s change in 100 m).

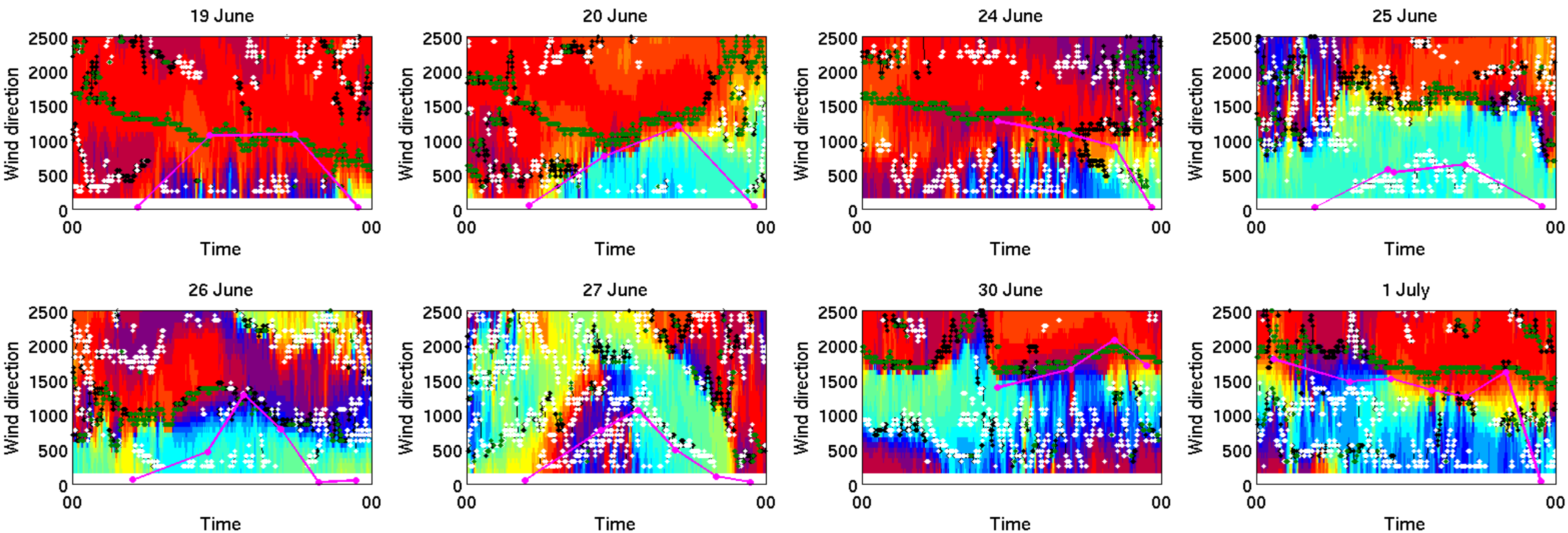
Strongest theta gradient from radiosounding shown in dark green.

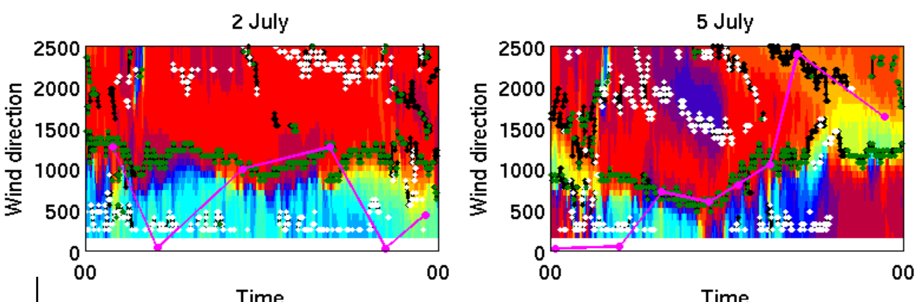
Borrowing some software from the Computational statistics community to smooth and gapfill data (but also apply some extra smoothing by running mean value procedures)

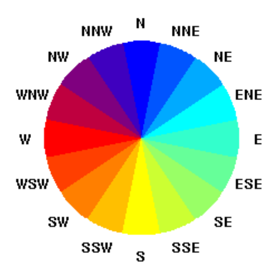
Garcia D, Robust smoothing of gridded data in one and higher dimensions with missing values. Computational Statistics & Data Analysis, 2010.

Wind direction from UHF

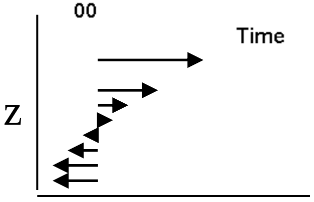
By Erik Nilsson







The strong wind gradient identification (green dots) most of the time separates the large-scale westerly flow that persist above form the often opposing easterly flow below



Idealized wind vectors

The figure emphasize the actual complexity that exist at the site

❑ Suggestions !

External driving pressure force grdP:
Presecribed constant geostrophic wind Ug.
Ug=F (z).
Ug=F (t).
Fixed flow velocity of a plane at a certain height.

!