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# Ship-based multi-sensor remote sensing and its potential for offshore wind research

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# Accurate wind energy estimate

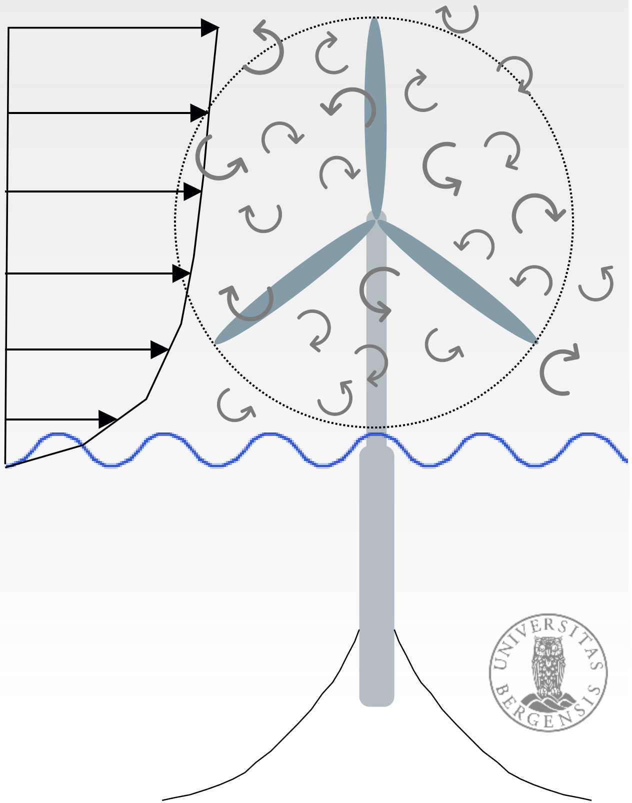
## *Measurements*

Wind climatology

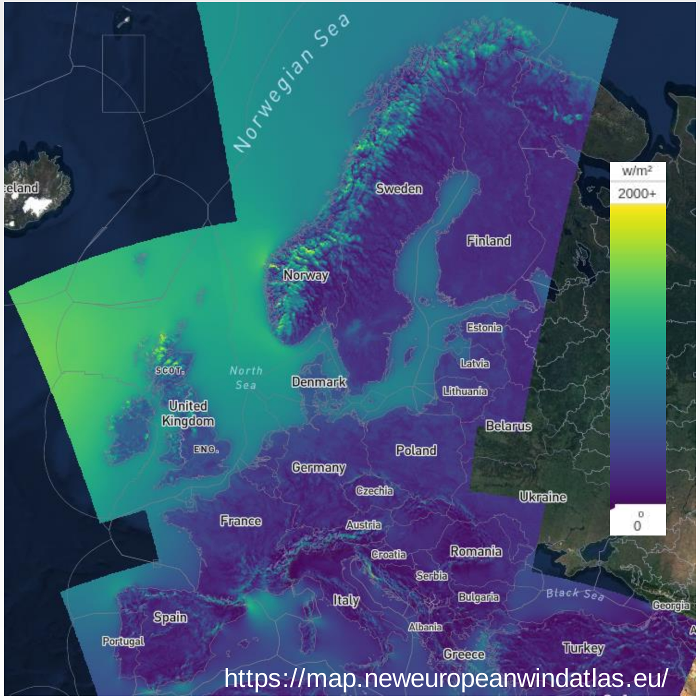
- wind shear over rotor disk (profile)
- turbulence information
- stability

## *Modelling*

- Database *statistical modelling* and *mashine learning* (see e.g. [1])
- improving Boundary Layer Models



## Offshore wind resource




https://map.neweuropeanwindatlas.eu/

See [2]

## Observation potential


https://www.pinterest.com/pin/399342691933426971/
https://en.wikipedia.org/wiki/Fjord_Line

# Ship-based remote sensing

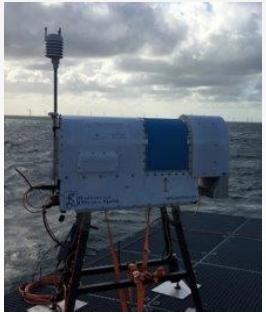
## *Core Instrumentation*


### ***Windcube V2 Lidar***

Radial velocities

Retrieval:
3D wind vector (u,v,w)

➜ Wind profile
➜ Turbulence

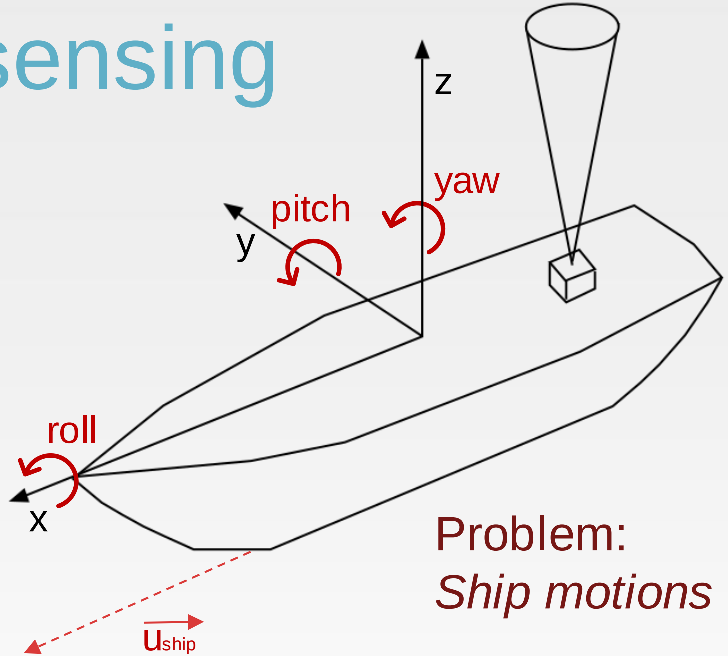


### ***HATPRO Radiometer***

Brightness Temperature

Retrieval:
Temperature, Humidity

➜ Stability



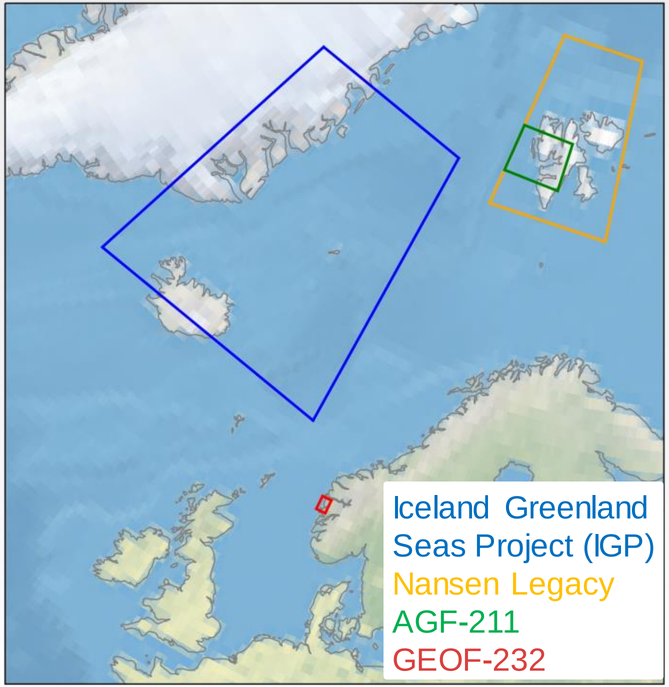

Problem:
*Ship motions*

Motion correction approaches:

➜ ***post*** and ***pre*** retrieval of 3D wind vector (see [3])

# Available infrastructure & Study Basis

*The Offshore Boundary Layer Observatory (OBLO)*




| | | |
|---|---|---|
| IGP | Feb-Mar 2018 | Iceland Greenland Seas |
| Nansen | Sep 2018 | Svalbard |
| GEOF-232 | Feb-Mar 2019 | Masfjord |
| AGF | Apr 2019 | Svalbard |

[4]

# Quality Control and Validation

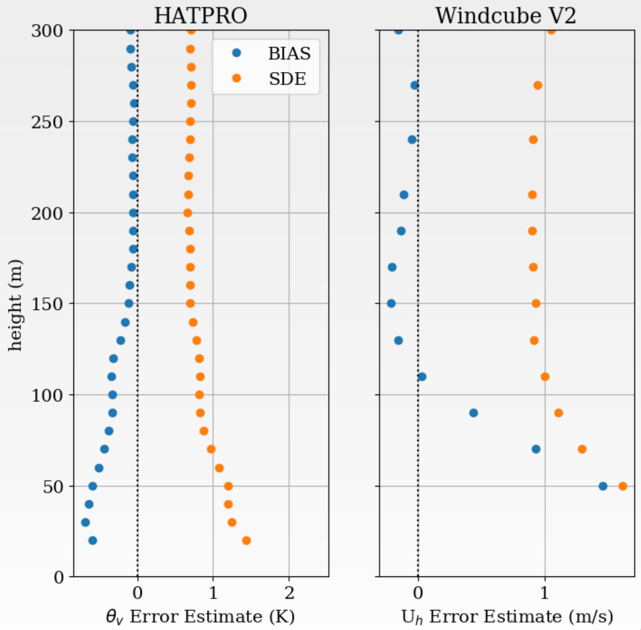
**Quality Control (flag/remove)**

- outliners
- unrealistic gradients
- missing values
- extrem ship motion
- precipitation, fog, low aerosol amount

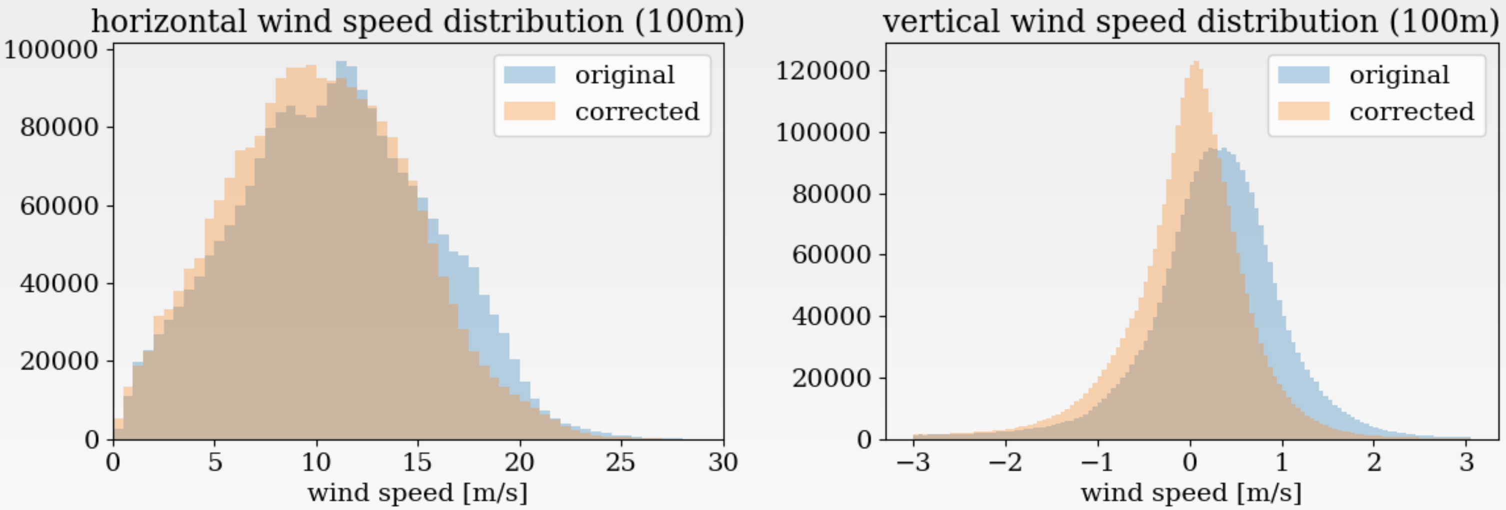
**Validation against Radiosondes**

- Relatively good agreement above 150m (HATPRO), 100m (Lidar)

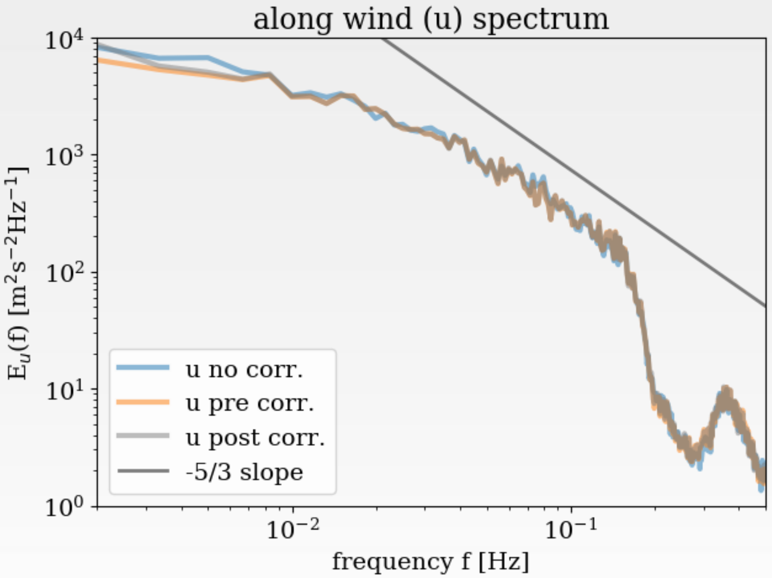
*Note: Generally low ws correlation with Radiosondes at low altitudes* [5]

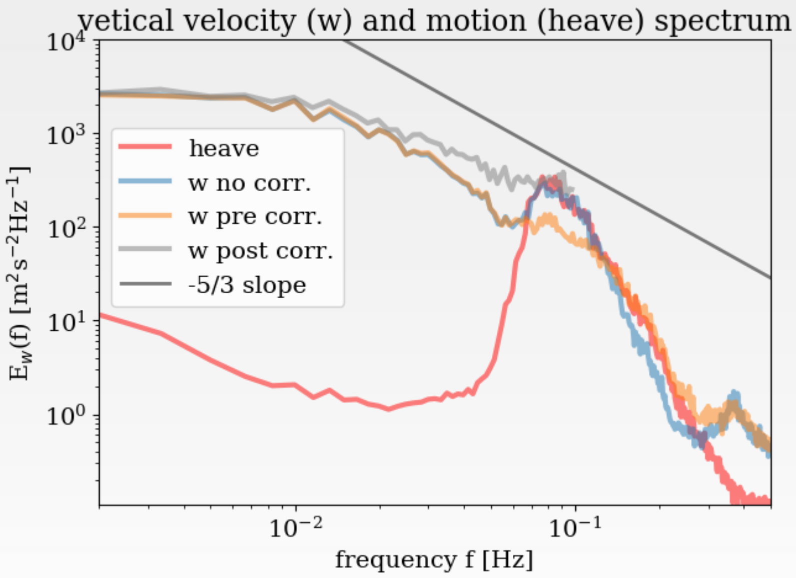


# Motion correction impact



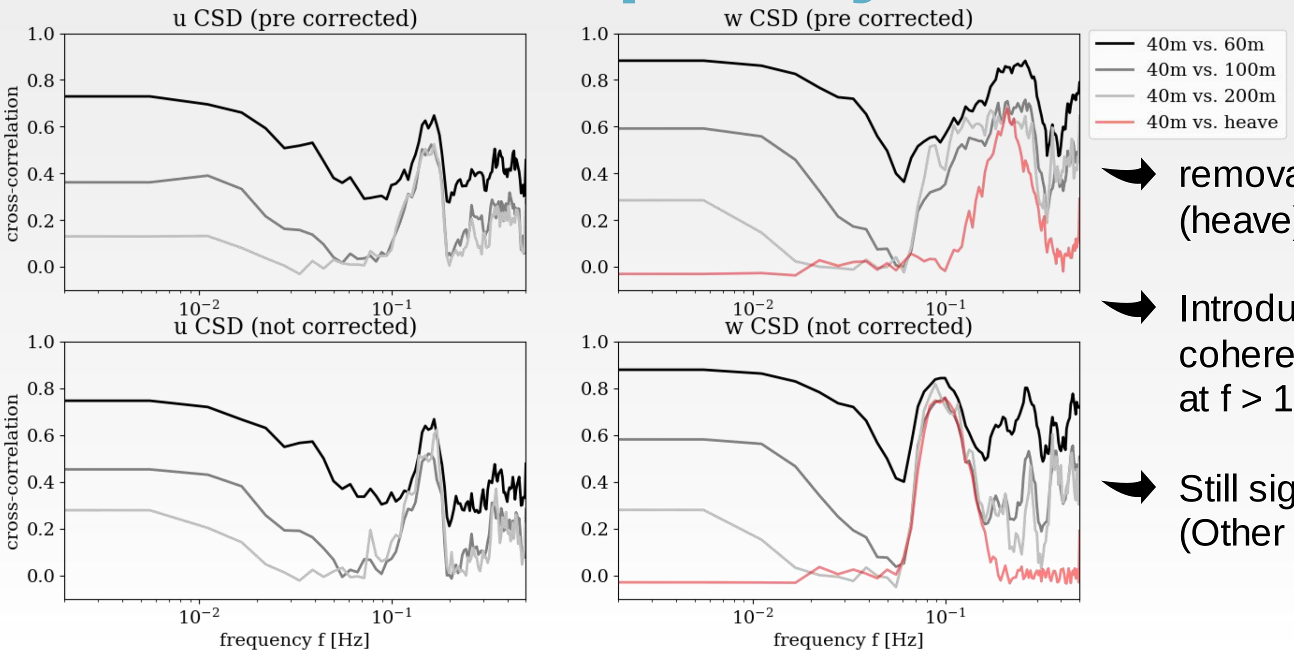
# Spectrum




*Ability of Lidar to measure Turbulence see [6]*

# Identifying the maximum resolvable frequency




- removal of motion signal (heave) f > $10^{-1}$Hz (Nyquist)
- Introduction of artificial coherence / spectral energy at f > $10^{-1}$Hz
- Still signal at f > 6*$10^{-2}$Hz (Other sources)

CSD: normalized cross spectral density → spectral co-coherence

# Application

## Lidar

*Wind profile*

- Horizontal wind shear
- Vertical velocity divergence

*Turbulence*

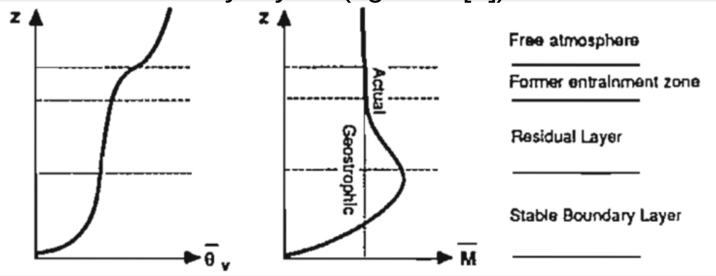
## Hatpro

*Temperature and Relative Humidity profiles*

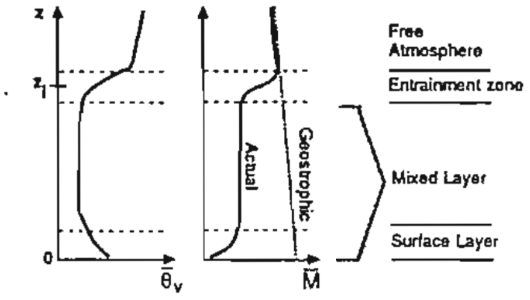
- stability profile

  ➜ often changing stability over observation range
- Boundary Layer Depth

"stable boundary layer" (fig.1.11 [7])




"convective boundary layer" (fig.1.9 [7])

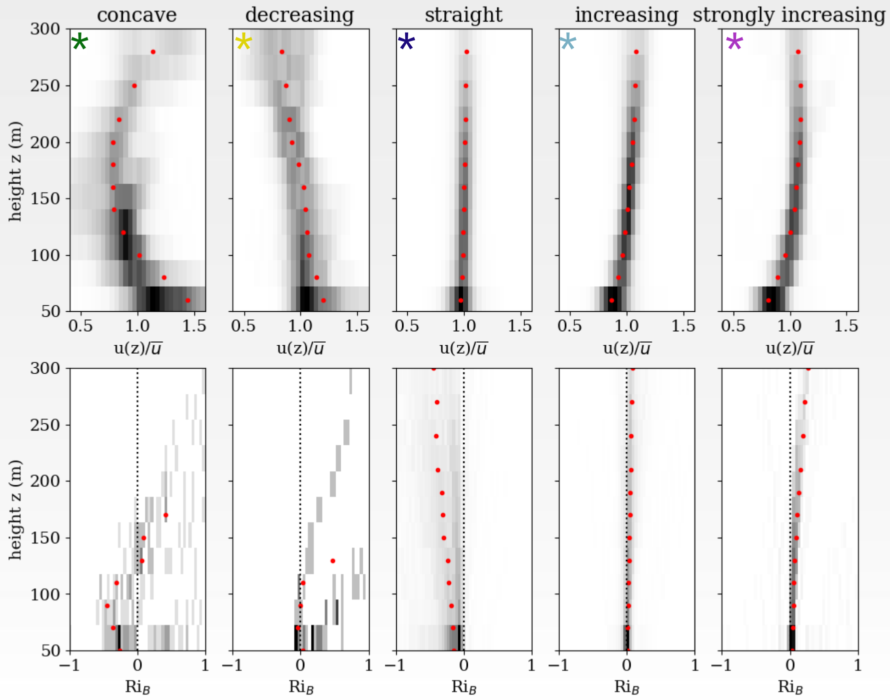



Idendifying marine boundary layer type

➜ Indirect information about Turbulence

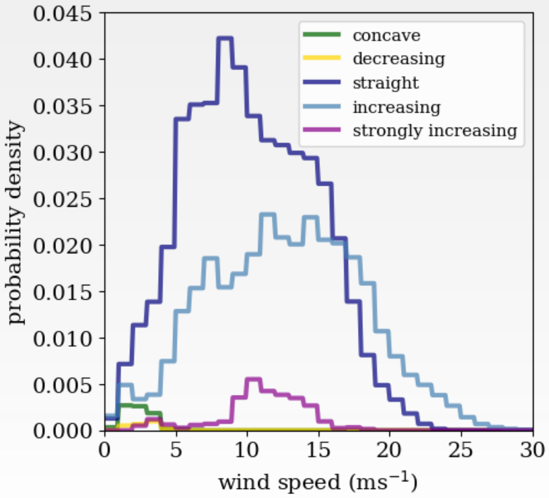
➜ e.g locating inertial subrage

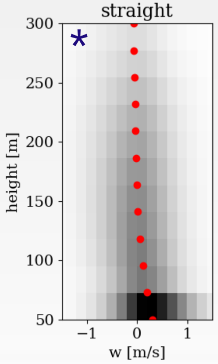
# Profile Classification




Classification by wind profile shape

➡ Parameters from least squares fit




[8],[9],[10]

Ri$_B$ requires additional information

➡ Sea surface temperature

# Summary

Quality of combined measurements (range: 50m-300m)

- Very promising between 100m and 200m altitude for:
  - ➙ Wind shear (50m-200m)
  - ➙ Stability estimate (100m-300m)
- Applicable for many future offshore wind energy applications (e.g. mashine learning)
- Still shortcomings in terms of Turbulence observations
  - ➙ Needs to be approximated from other obsevations

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