OFFSHORE ATMOSPHERIC STABILITY ESTIMATION FROM FLOATING LIDAR WIND PROFILES

Araujo da Silva, M. P.[1], *Rocadenbosch, F.*[1,2], *Farré-Guarné, J.*[1], *Salcedo-Bosch, A.*[1], *González-Marco, D.*[3,4], *and Peña, A.*[5]

[1] **CommSensLab-UPC, Department of Signal Theory and Communications (TSC), Universitat Politècnica de Catalunya (UPC), Barcelona, Spain;**

[2] Institut d'Estudis Espacials de Catalunya (Institute of Space Studies of Catalonia, IEEC), Barcelona, Spain;

[3] Laboratori d'Enginyeria Marítima, **UPC**, Barcelona, Spain;

[4] Centre Internacional d'Investigacio dels Recursos Costaners (CIIRC), Barcelona, Spain;

[5] **DTU Wind Energy**, Roskilde, Denmark.

Correspondence: marcos.silva@upc.edu (M.P.A.S.); roca@tsc.upc.edu (F.R.)

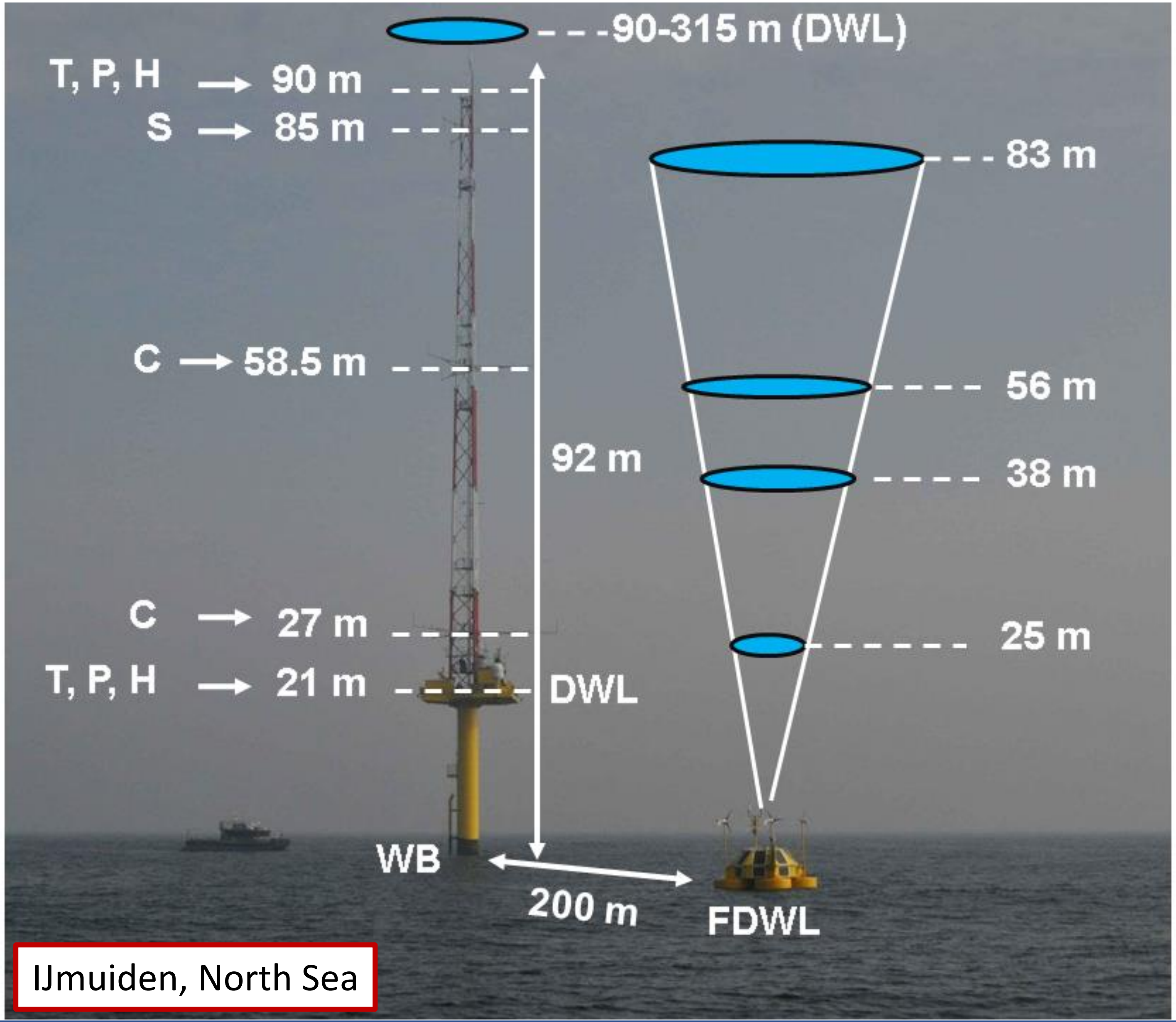
EGU General Assembly 2022

OBJECTIVE

- Assess atmospheric stability from floating Doppler wind lidar (FDWL).
  - ✓ Power performance, wind shear, and wakes.
- Mast-measured reference parameters used to evaluate performance of the stability estimation algorithm.
- 82-day campaign → 10,822 10-min samples

SENSORS

FDWL → Zephir™ 300.
(T) Temperature sensor.
(P) Pressure sensor.
(H) Humidity.
(S) Sonic anemometer.
(C) Cup anemometer.
(WB) Wave and current buoy.



2D-algorithm estimated stability (FDWL)

FDWL data screening

- HWS < 2 or HWS > 70 [m/s]
- Spatial variation: confidence interval of 95%
- N = 8263 10-min samples.

↓

FDWL-measured wind profile

MOST wind-profile model; Businguer-Dyer functions: $U(z, u_*, L)$,

$\vec{U}_{FDWL}(z)$ (z = 25, 38, 56 and 85 m)

$\vec{U}(z)$

Non-linear least squares

$$\underset{L,u_*}{\arg\min}\left|\vec{U}_{FDWL} - \vec{U}(z)\right|^2$$

↓

10-min $\hat{L}$ and $\hat{u}_*$

Araújo da Silva et al. (2022)

Reference stability (Mast)

Temperature observations from sonic anemometers were not stored

↓

Grachev and Fairall (1997)

T_{21} → Temperature at 21 m
T_0 → Temperature from wave buoy at 0 m
U_{27} → HWS at 27 m

→ Bulk Richardson number

↓

Dimensionless stability, $\zeta(R_i)$

↓

$z' = 15.5$ m → $L_{Ri} = \frac{z'}{\zeta}$

Stability classification for the whole campaign

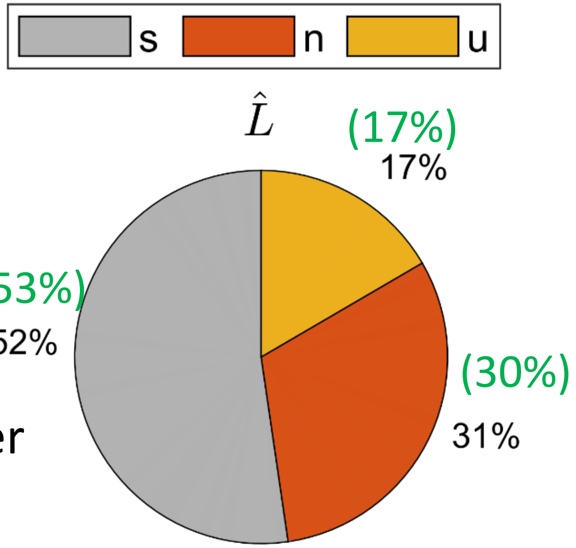
Table 1. Stability classes based on the Obukhov length, L.

Atmospheric Stability	Obukhov length range (m)
Stable	$10 < L < 500$
Neutral	$\lvert L \rvert > 500$
Unstable	$-500 < L < -50$

5,922 valid samples

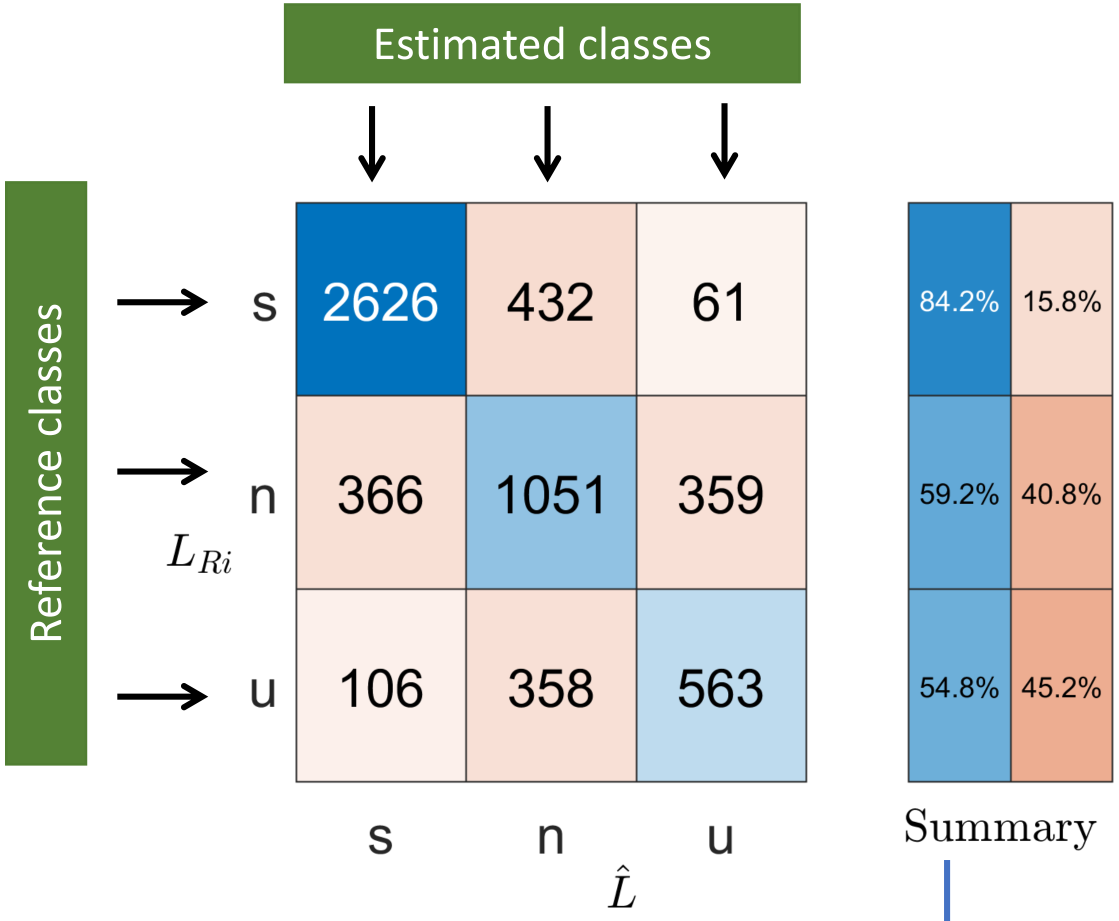
Gryning et al. (2007)

- s: stable
- n: neutral
- u: unstable



Green: Richardson number
Black: from 2D (FDWL)

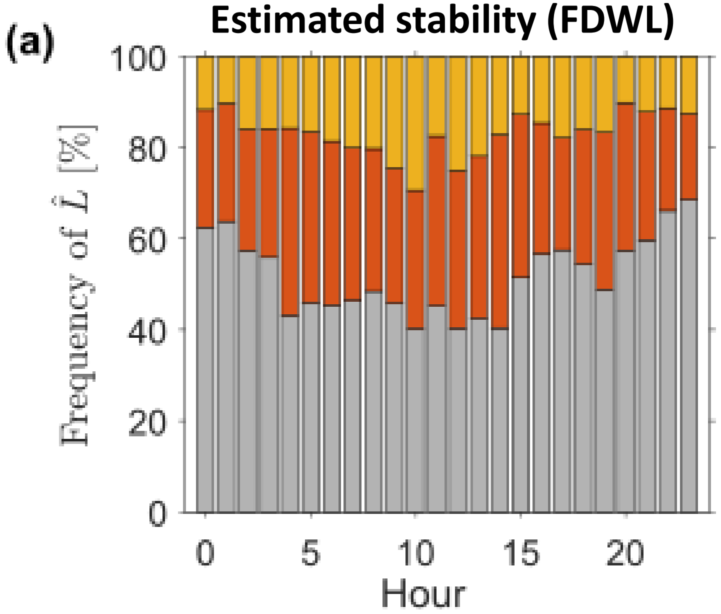
Confusion matrix



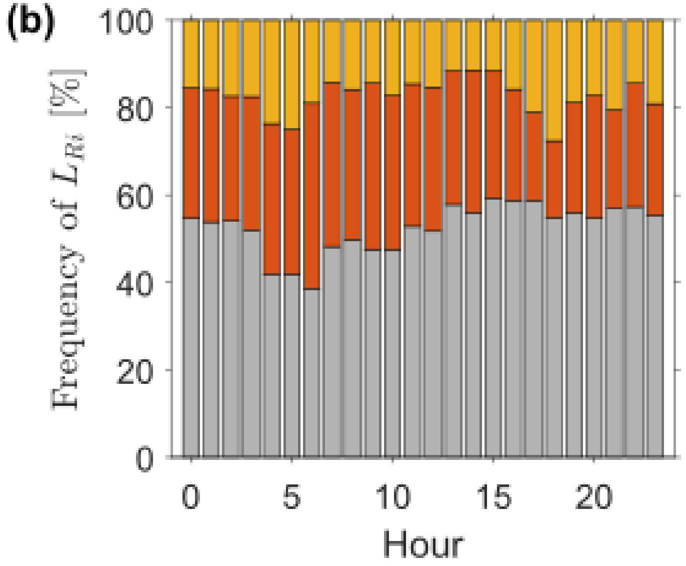
Mean hit rate: ~66%

Stability classification **clustered by hour of the day**

Estimated stability (FDWL)



Reference stability (Richardson number)



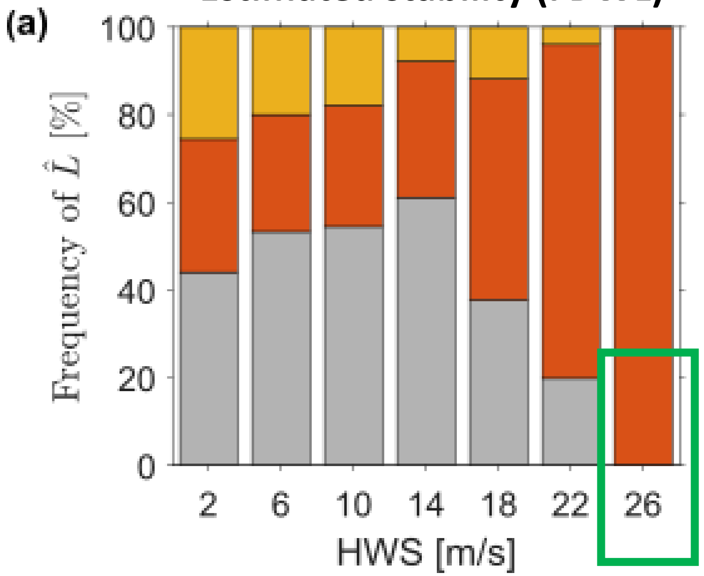
s: stable → 10 < L < 500

n: neutral → |L|> 500

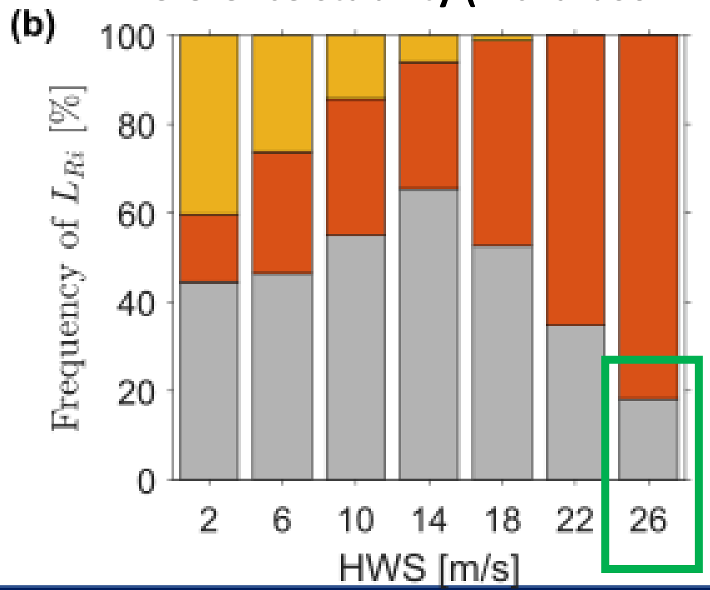
u: unstable → -500 < L < -50

Stability classification **clustered by horizontal wind speed (HWS)**

Estimated stability (FDWL)



Reference stability (Richardson number)



Stable class is underestimated at 26-m/s cluster

CONCLUSIONS

- A 2-D algorithm for *atmospheric stability classification* was derived.
- The algorithm consists of fitting the MOST wind profile model to the FDWL-measured wind profile via non-linear LSQ optimization.
  - Relies on estimation the *friction velocity* and *Obukhov length* (semi-quantitative).*
    → aiming to classify the atmospheric stability in *three classes*.
  - Confusion matrix → Mean HIT RATE = 66%.
- The 2-D algorithm enabled to assess:
  - The stability evolution during the time of day.
  - The horizontal-wind-speed dependence on the stability.

ACKNOWLEDGMENTS

- Ministerio de Ciencia e Investigación (MCIN)/Agencia Estatal de Investigación (AEI)/10.13039/501100011033/ FEDER "Una manera de hacer Europa", projects PGC2018-094132-B-I00 and MDM2016-0600 ("CommSensLab" Excellence Unit)
- The work of M.P Araujo da Silva was supported under Grant PRE2018-086054 funded by MCIN/AEU/ 10.13039/501100011033 and FSE "El FSE invierte en tu future".
- The work of A. Salcedo-Bosch was supported under grant 2020 FISDU 00455 funded by Generalitat de Catalunya—AGAUR.
- European Commission, projects H2020 ACTRIS-IMP (GA-871115) and H2020 ATMO-ACCESS (GA-101008004).

PRESENTATION REFERENCES

Araújo da Silva, M.P.; Rocadenbosch, F.; Farré-Guarné, J.; Salcedo-Bosch, A.; González-Marco, D.; Peña, A. "Assessing Obukhov Length and Friction Velocity from Floating Lidar Observations: A Data Screening and Sensitivity Computation Approach". Remote Sens. 2022, 14, 1394. https://doi.org/10.3390/rs14061394

Businger, Joost A., John C. Wyngaard, Y. Izumi, and Edward F. Bradley. "Flux-profile relationships in the atmospheric surface layer." *Journal of Atmospheric Sciences* 28, no. 2 (1971): 181-189.

Dyer, A.. "A review of flux-profile relationships." *Boundary-Layer Meteorology 7*, no. 3 (1974): 363-372.

Grachev, A. A., and C. W. Fairall. "Dependence of the Monin–Obukhov stability parameter on the bulk Richardson number over the ocean." *Journal of Applied Meteorology* 36, no. 4 (1997): 406-414.

Gryning, Sven-Erik, Ekaterina Batchvarova, Burghard Brümmer, Hans Jørgensen, and Søren Larsen. "On the extension of the wind profile over homogeneous terrain beyond the surface boundary layer." *Boundary-Layer Meteorology* 124, no. 2 (2007): 251-268.

Holtslag, M. C., W. A. A. M. Bierbooms, and G. J. W. Van Bussel. "Validation of surface layer similarity theory to describe far offshore marine conditions in the Dutch North Sea in scope of wind energy research." *Journal of Wind Engineering and Industrial Aerodynamics* 136 (2015): 180-191.

Thanks!

EXTRA SILDES

2D estimated stability (FDWL)

FDWL data screening

- HWS < 2 or HWS > 100 [m/s]
- Spatial variation: confidence interval of 95%
- N = 8263 10-min samples.

FDWL-measured wind profile

$\vec{U}_{FDWL}(z)$
(z = 25, 38, 56 and 85 m)

α=0.012

$$U(z) = \frac{u_*}{k}\left[ln\left(\frac{gz}{\alpha u_*^2}\right) - \psi\left(\frac{z}{L}\right)\right]$$

$\vec{U}(z)$

Non-linear least Squares

$$\underset{L,u_*}{\arg\min}\left|\vec{U}_{FDWL} - \vec{U}(z)\right|^2$$

10-min: $\hat{L}$ **and** $\hat{u}_*$

Reference stability (Mast)

T_{21} → Temperature at 21 m
T_0 → Temperature from wave buoy at 0 m
U_{27} → HWS at 27 m

$$Ri = \frac{g\Delta\bar{\theta}_v\Delta z}{\bar{\theta}_{v_{21}}(\bar{U}_{27})^2}$$

$\zeta = 10Ri$, if Ri $\leq$ 0

$\zeta = \frac{10Ri}{1-5Ri}$, if Ri $\geq$ 0

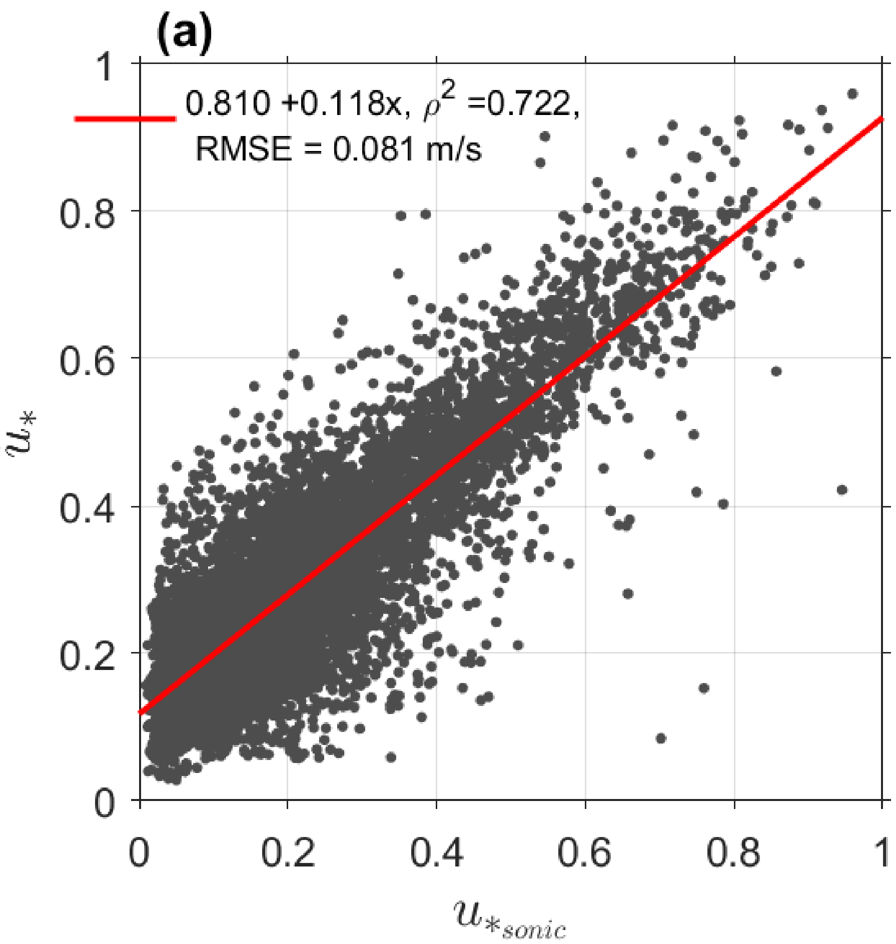
Grachev and Fairall (1997)

$z' = 15.5$ m

$$L_{Ri} = \frac{z'}{\zeta}$$

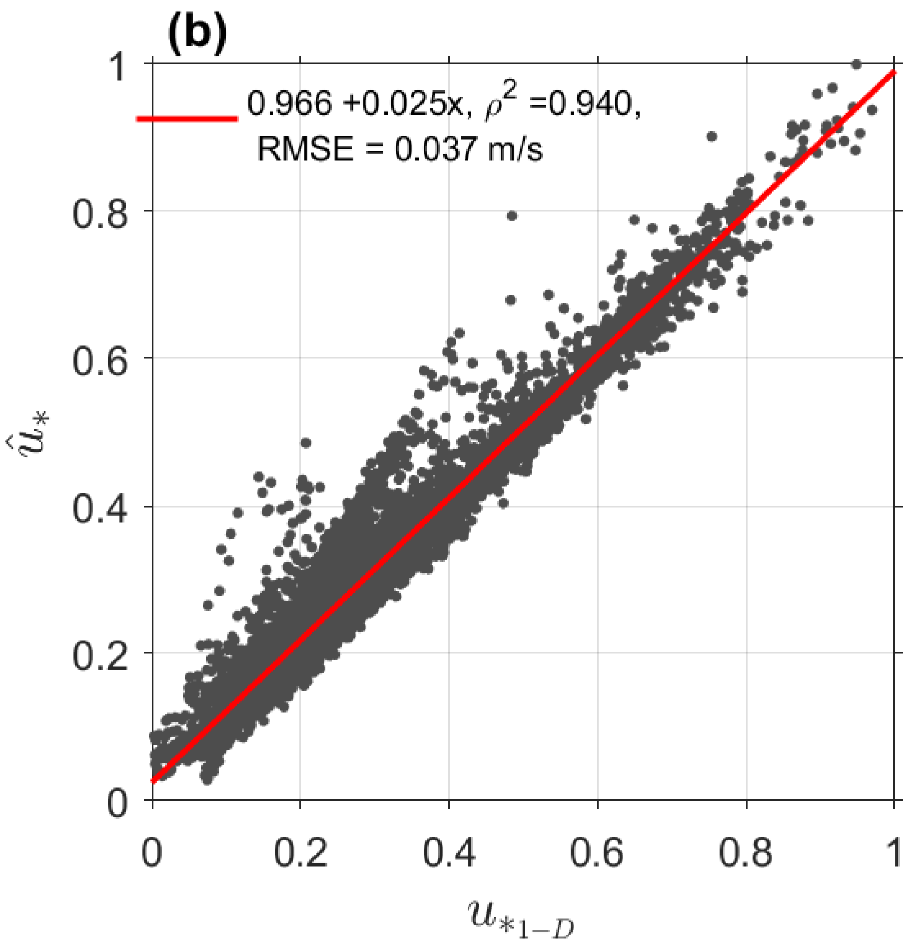
T_{21} → Temperature at 21 m
T_0 → Temperature from wave buoy at 0 m
U_{27} → HWS at 27 m

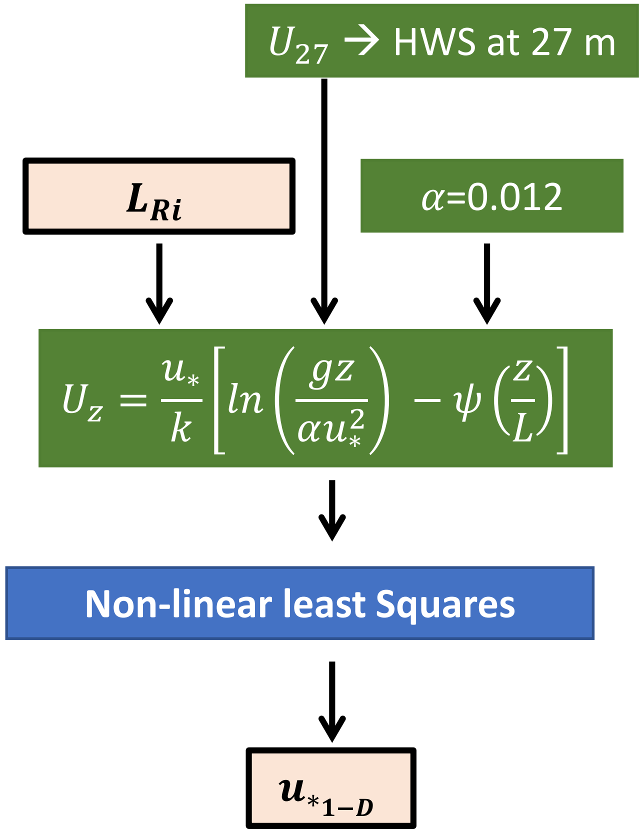
Reference: Sonic anemometers



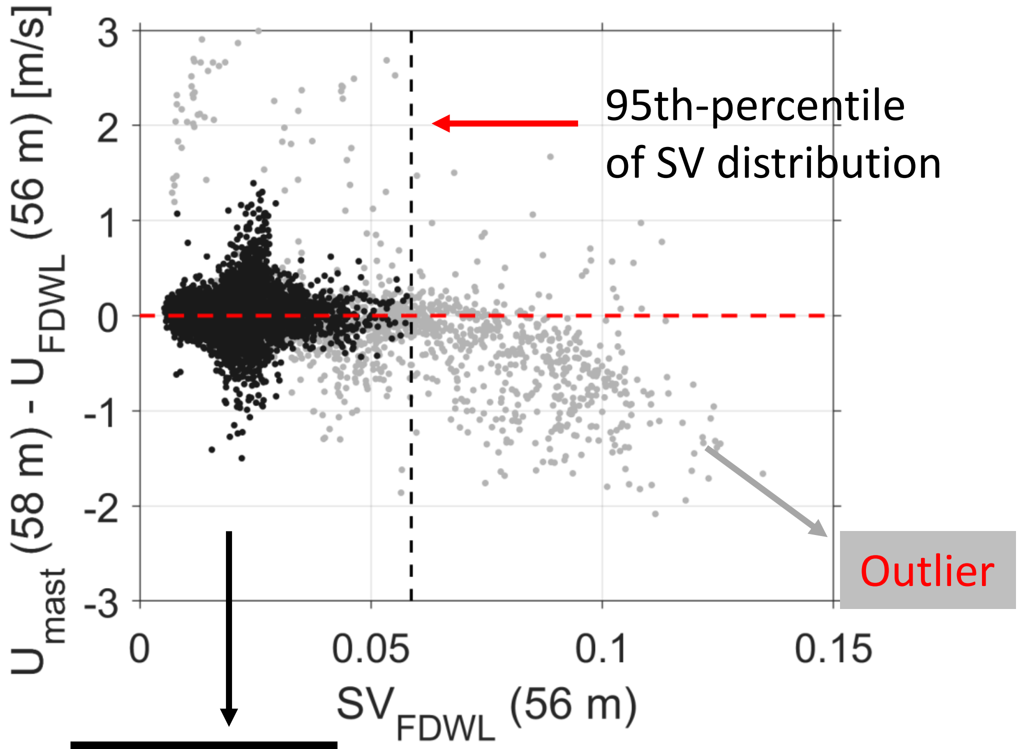
$$u_{*sonic} = \left(\overline{u'w'}^2 + \overline{v'w'}^2\right)^{0.25}$$

Reference: u_* numerically solved using





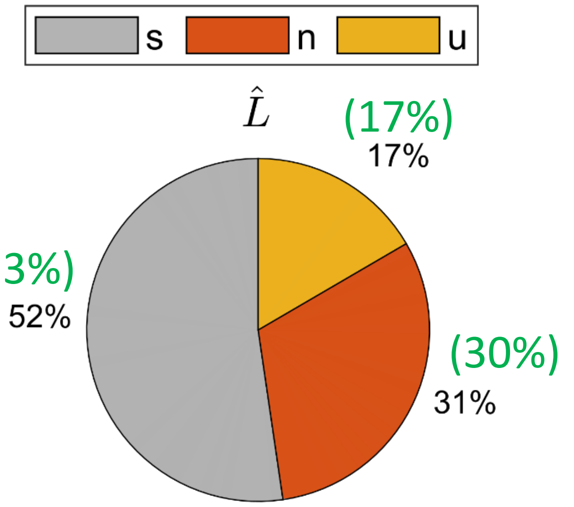
Data screening



Valid samples → 95%
Outlier samples → 5%
Spatial variation → lidar fitting quality

Stability classification for the whole campaign

- s: stable
- n: neutral
- u: unstable



Green: L from Richardson number
Black: L from FDWL

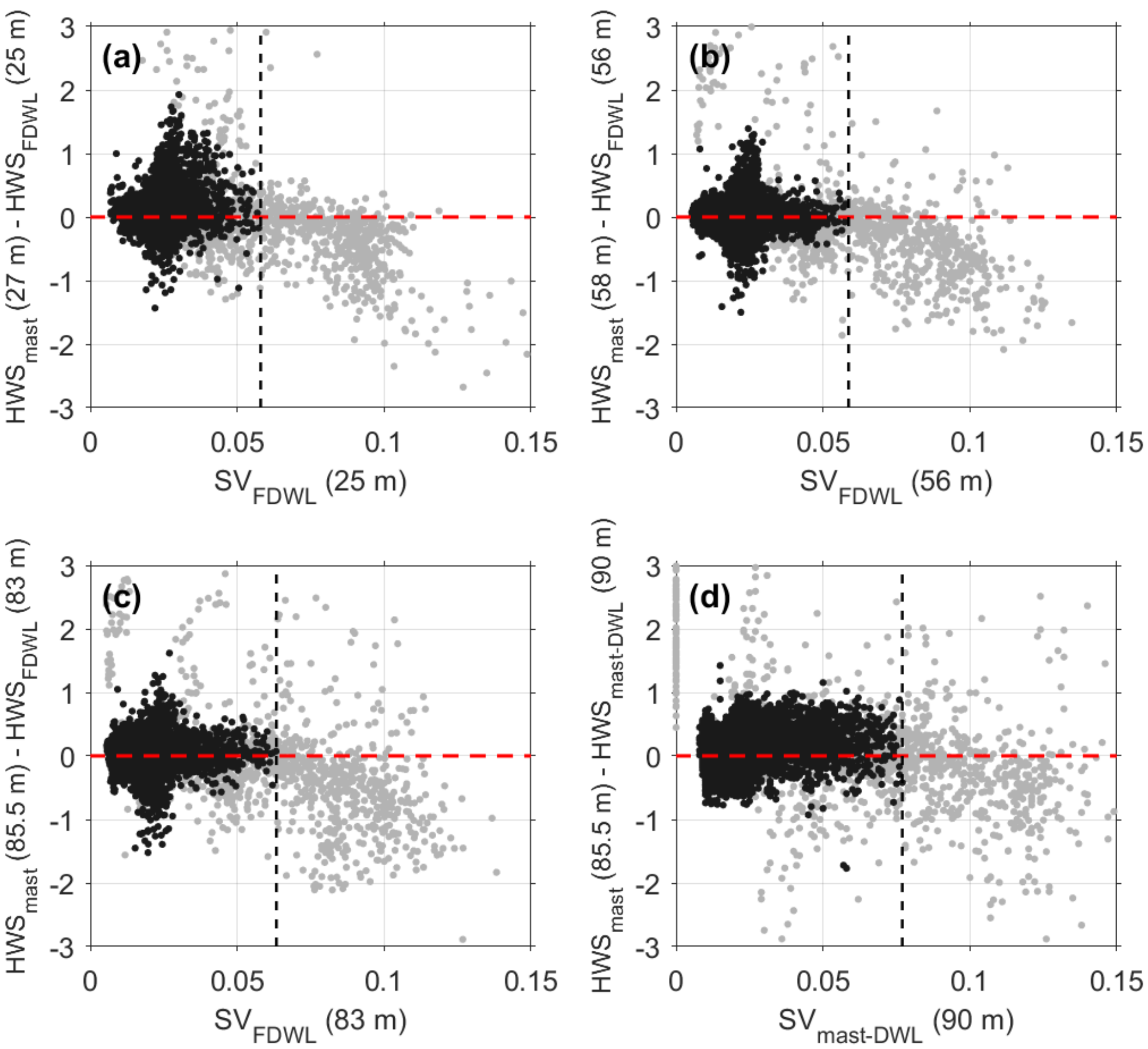
Confusion matrix

Mean hit rate: ~66%

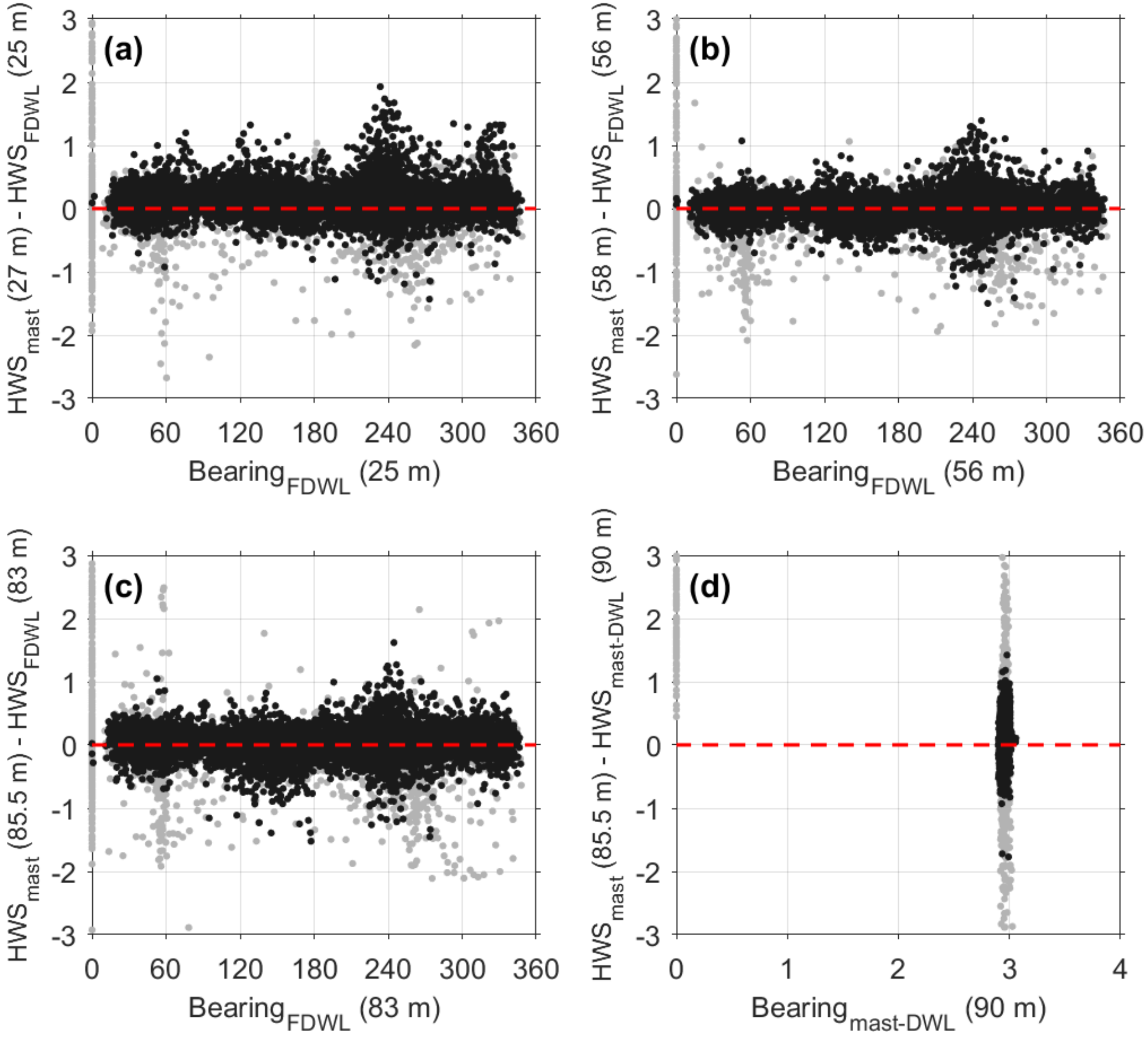
L_{Ri} \ $\hat{L}$	s	n	u	Summary	
s	2626	432	61	84.2%	15.8%
n	366	1051	359	59.2%	40.8%
u	106	358	563	54.8%	45.2%

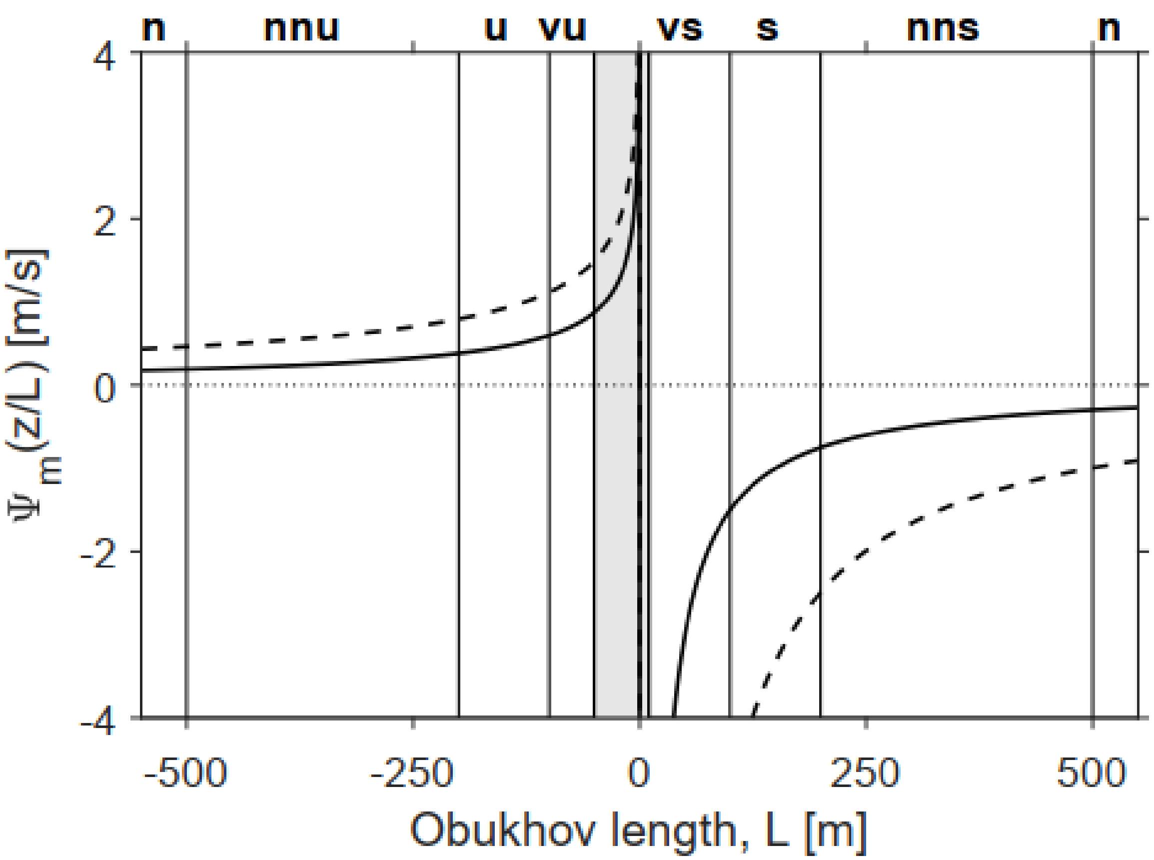
EXTRA SILDES

Data screening



Data screening





Araújo da Silva et at. (2022)

Figure 2. Stability-correction function $\Psi_m(\frac{z}{L})$ as function of Obukhov's length for $z = 27$ m (thick-solid line) and $z = 83$ m (dashed line). (Vertical grey-shaded) area delimits the interval from $L = -50$ m to $L = 10$ m. (Vertical lines) delimit Gryning et al. [35] stability-classification thresholds as per Table 2. Labels: (vu) very unstable, (u), unstable, (nnu), near-neutral unstable, (n), neutral, (nns) near-neutral stable, (s) stable and (vs) is very stable.