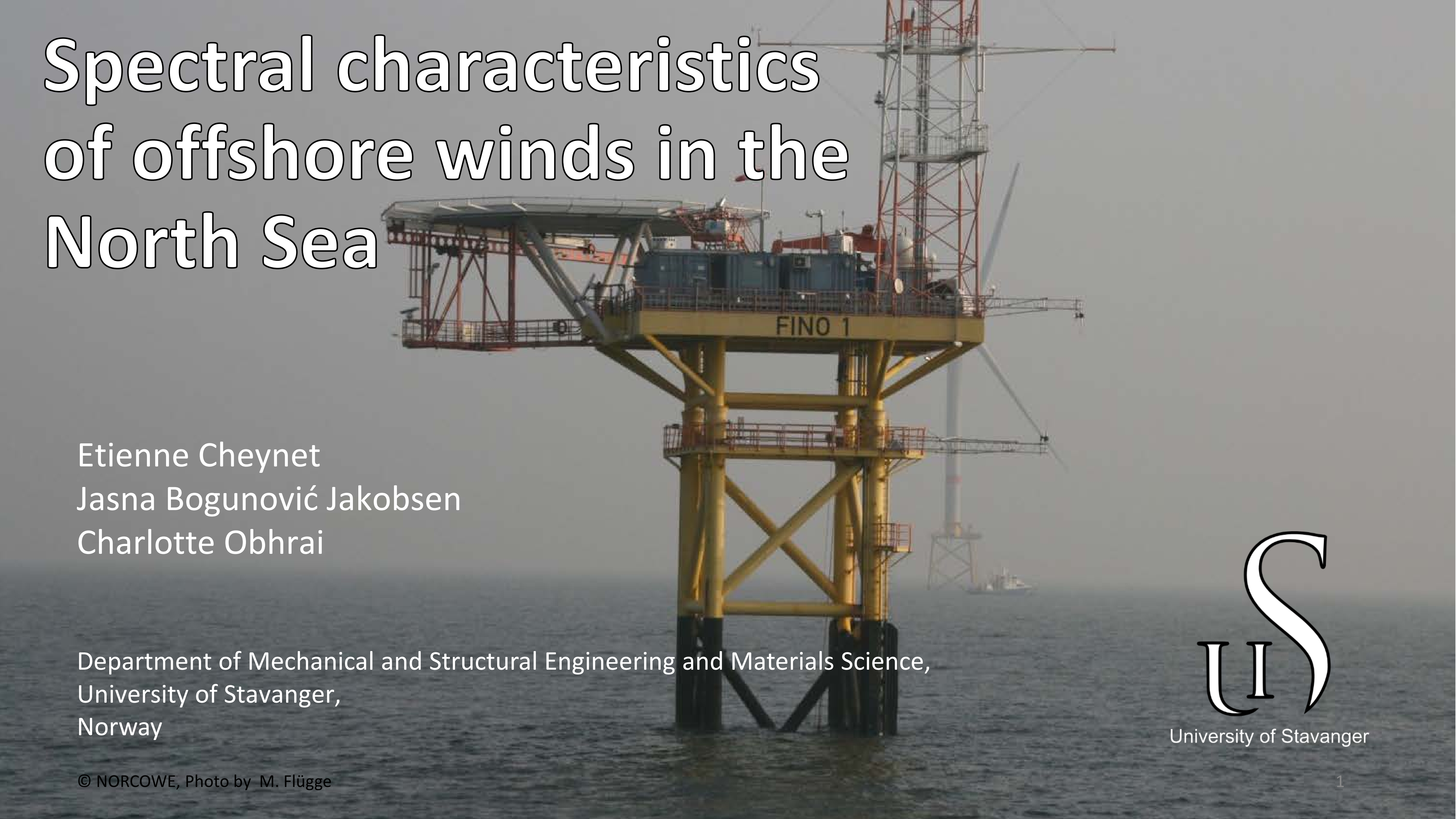
Spectral characteristics of offshore winds in the North Sea



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Do the wind spectra proposed in

IEC 61400 [1,2] apply well in the North sea ?

1. *IEC 61400-1 Wind turbines Part 1: Design requirements; 2005*
2. *IEC 61400-3, . Wind Turbines Part 3: Design Requirements for Offshore Wind Turbines; 2009.*

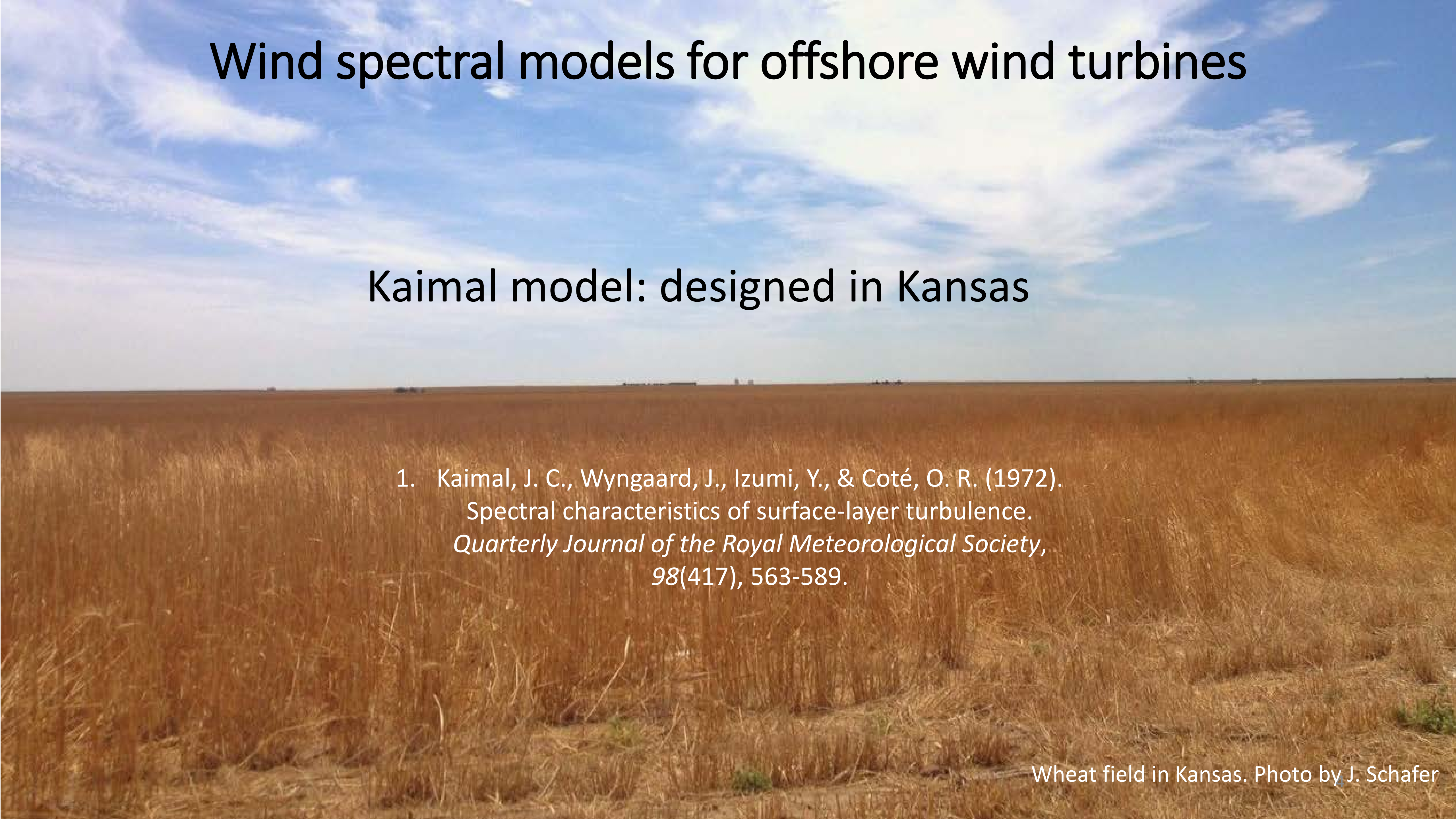
Organisation of the presentation

1. Wind spectra studied
2. Data processing
3. Comparison of the wind spectra in the field and those in standards

Wind spectral models for offshore wind turbines

Kaimal model: designed in Kansas

1. Kaimal, J. C., Wyngaard, J., Izumi, Y., & Coté, O. R. (1972). Spectral characteristics of surface-layer turbulence. *Quarterly Journal of the Royal Meteorological Society*, *98*(417), 563-589.

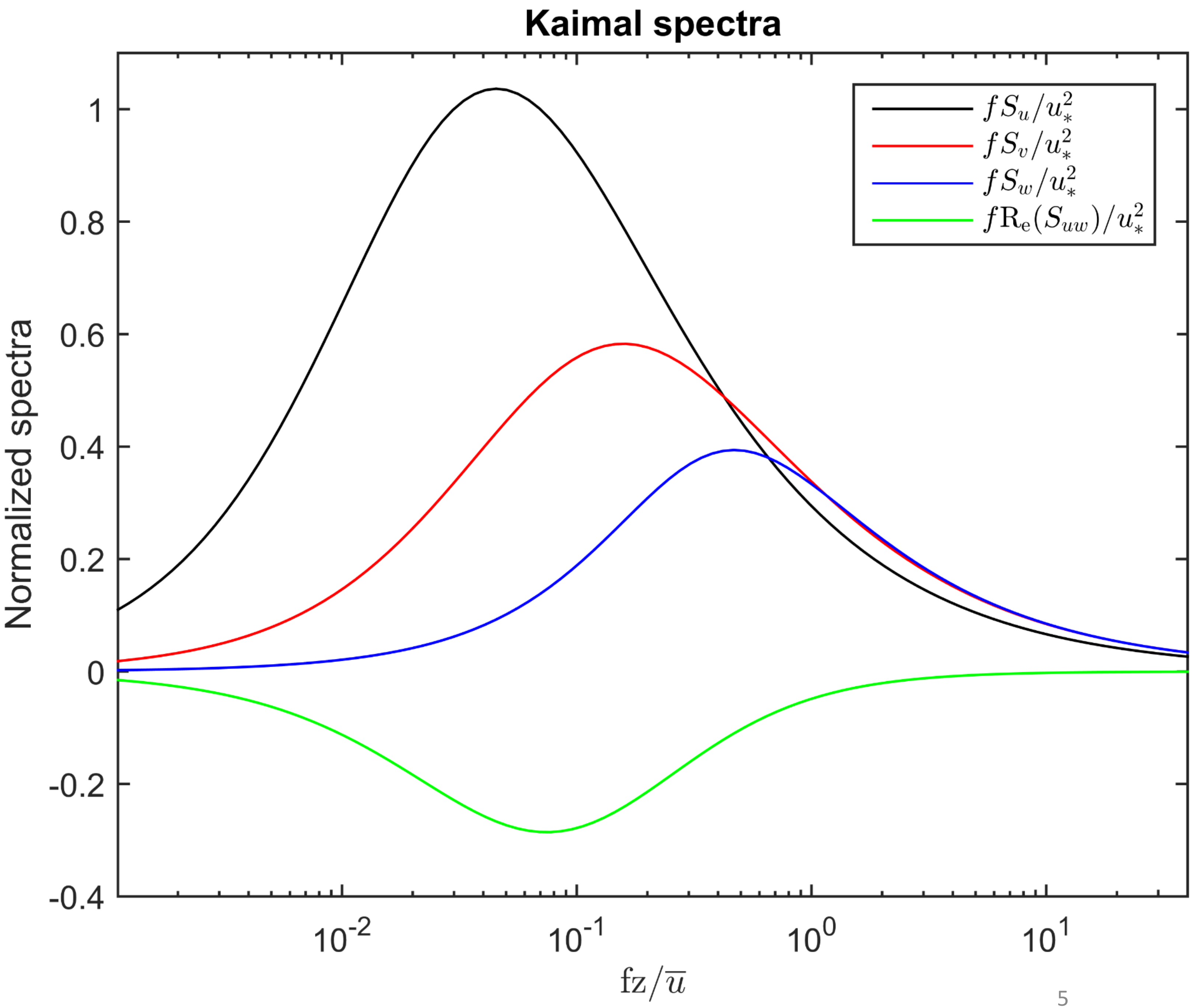


Wheat field in Kansas. Photo by J. Schafer

Wind spectral models for offshore wind turbines

$$u_* = [(uw)^2 + (uv)^2]^{\frac{1}{4}}$$

Kaimal, J. C., Wyngaard, J., Izumi, Y., & Coté, O. R. (1972). Spectral characteristics of surface-layer turbulence. *Quarterly Journal of the Royal Meteorological Society*, *98*(417), 563-589.



"Original Kaimal spectrum"
For *u* component

$$\frac{f\,S_u}{u_*^2} = \frac{105\,n}{(1+33\,n)^{5/3}}$$

$$n = \frac{fz}{\bar{u}}$$

"IEC Kaimal spectrum"
For *u* component

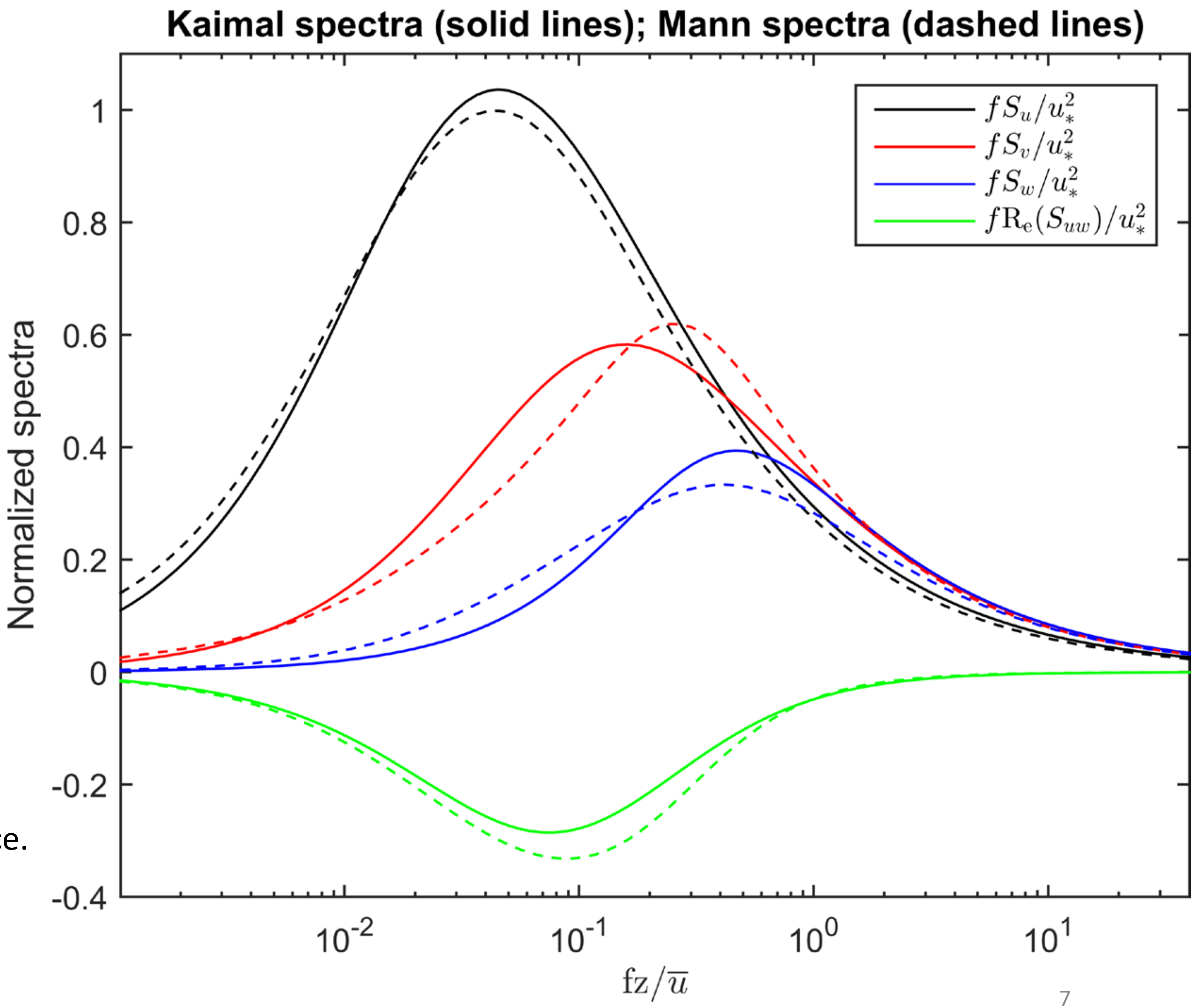
$$\frac{f\,S_u}{\sigma_u^2} = \frac{4\,f_r}{(1+6\,f_r)^{5/3}}$$

$$f_r = \frac{f\,L_u}{\bar{u}}$$

$$L_u = 8.1\,\Lambda_1$$

$$\Lambda_1 = 42\text{ m (at } z = 80\text{ m)}$$

Wind spectral models for offshore wind turbines



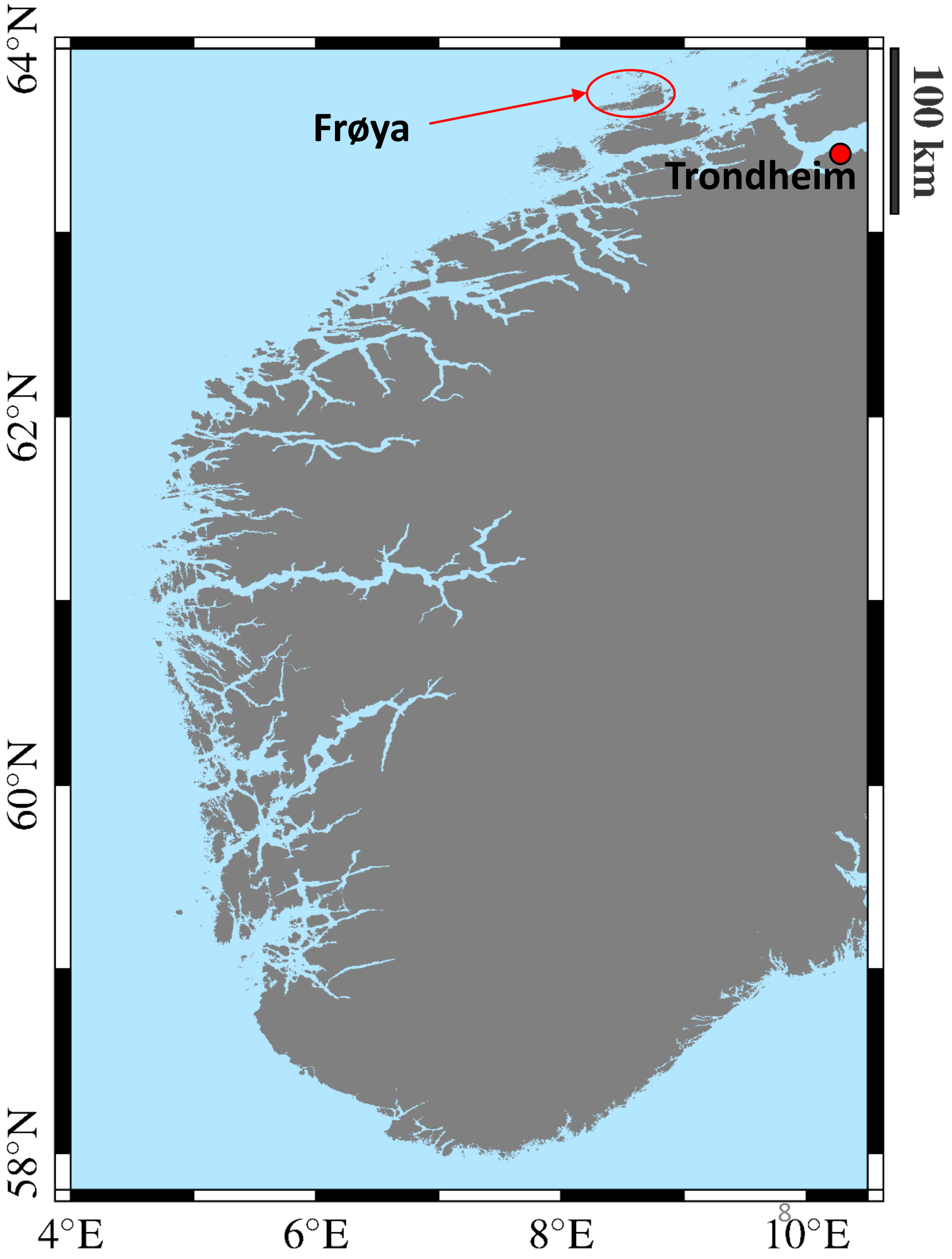
Mann, J. (1994). The spatial structure of neutral atmospheric surface-layer turbulence. *Journal of fluid mechanics*, *273*, 141-168.

NORSOK standard

$$S_u(f) = 320 \left(\frac{\bar{u}}{10}\right)^2 \left(\frac{z}{10}\right)^{0.45} (1 + A^m)^{-\frac{5}{3m}}$$

$$A = 172\, f \left(\frac{\bar{u}}{10}\right)^{-0.75} \left(\frac{z}{10}\right)^{2/3}$$

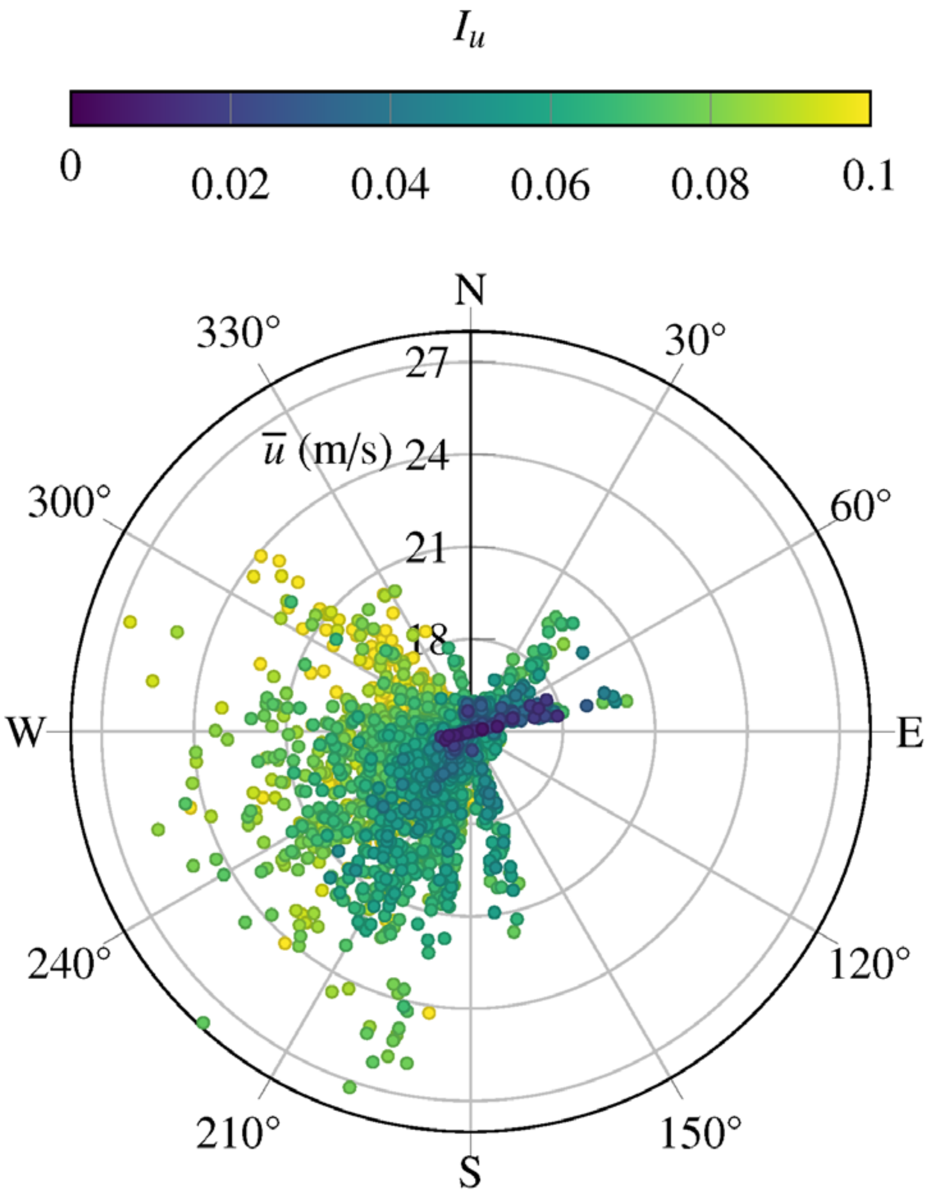
$$m = 0.468$$



Andersen, O. J., & Løvseth, J. (2006). The Frøya database and maritime boundary layer wind description. *Marine Structures*, *19*(2), 173-192.

NORSOK standard

Wind measurement overview

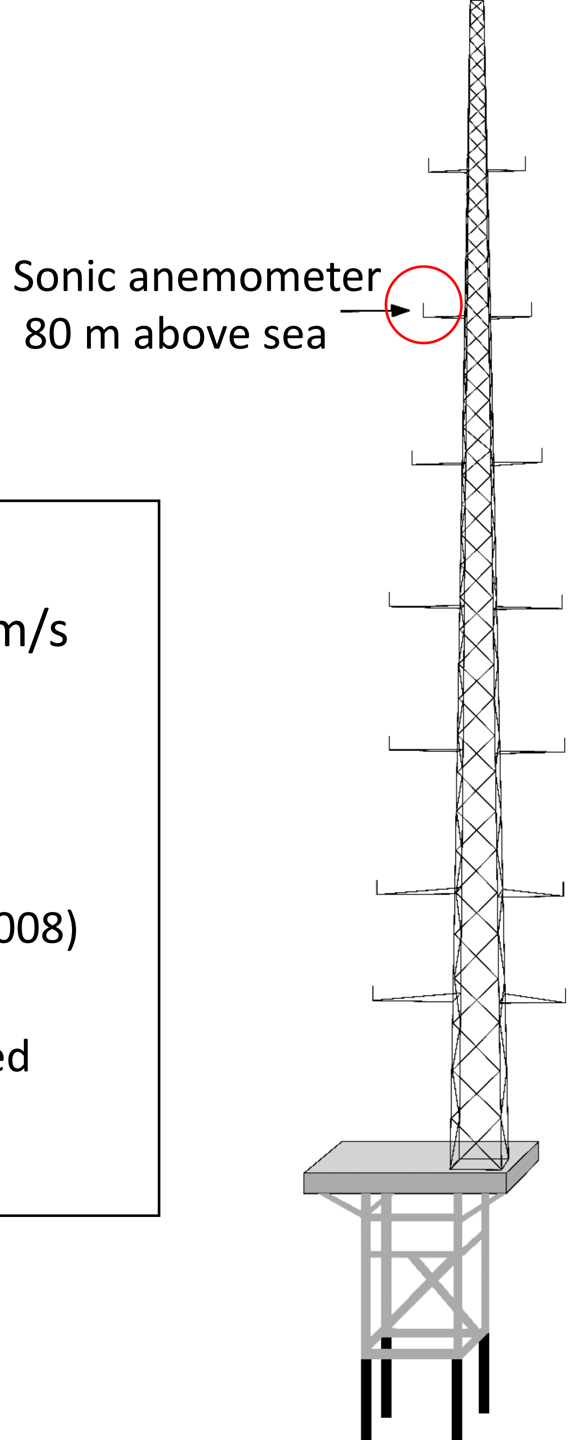


$14\text{ m/s} \leq \overline{u} \leq 28\text{ m/s}$

Averaging time: 1 h

2 years of data (2007-2008)

u, v and *w* are studied



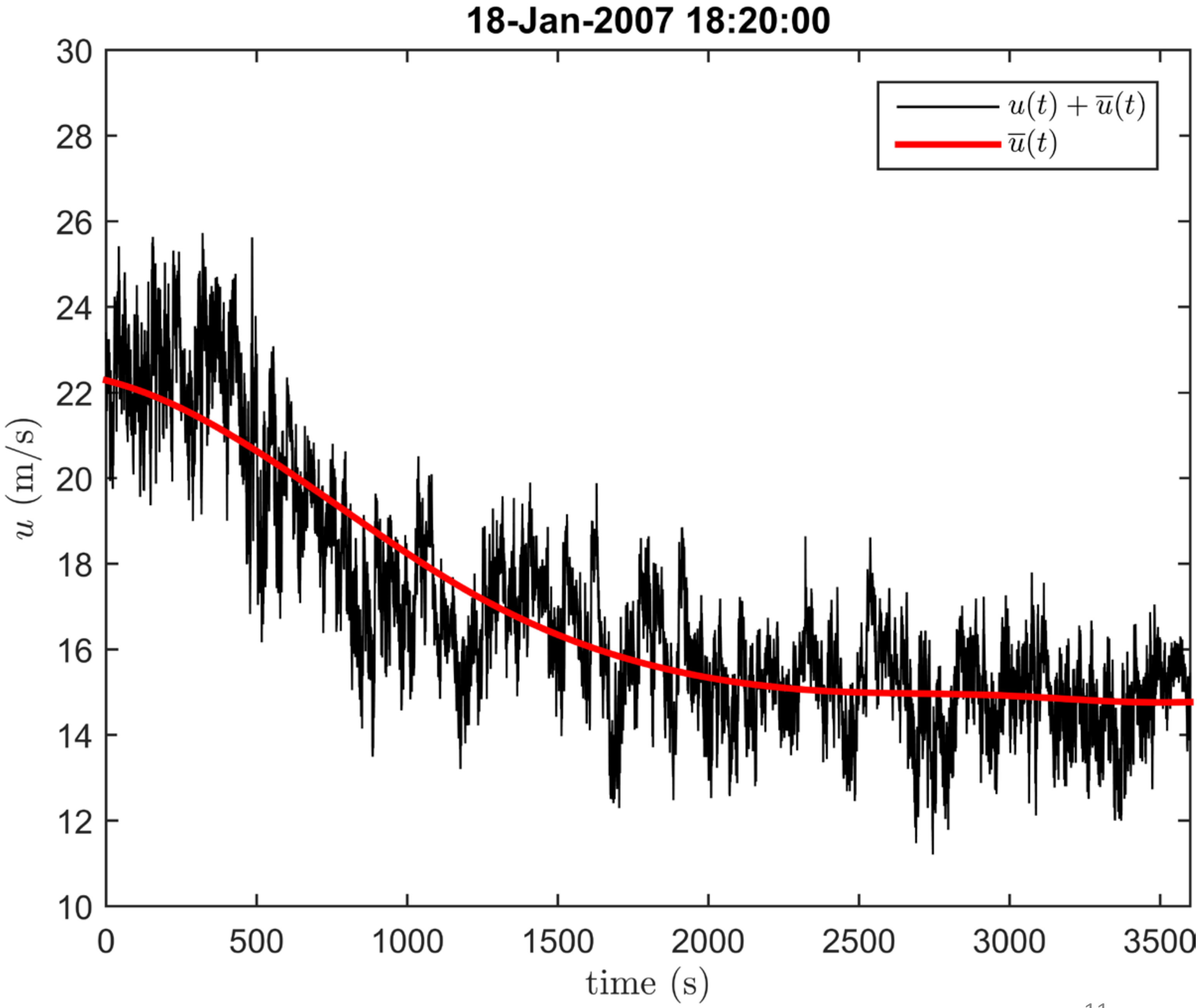
Data pre-processing

Non-stationary wind model
with time-varying mean extracted using the Empirical model decomposition (EMD).

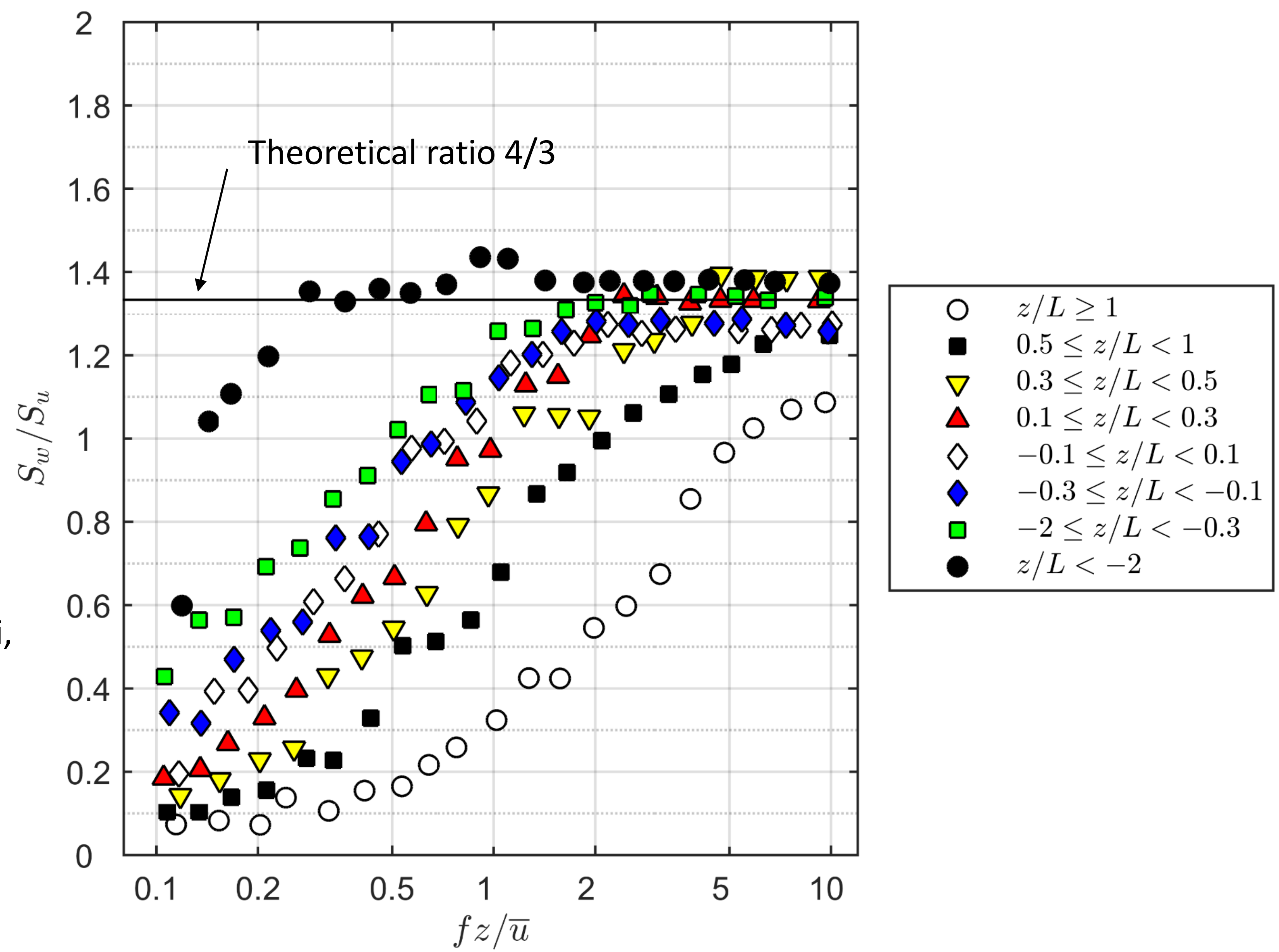
+

Stationary test conducted with Reverse arrangement test [1]

[1] Bendat, J. S., & Piersol, A. G. (2011). *Random data: analysis and measurement procedures* (Vol. 729). John Wiley & Sons.



Selection of neutral wind conditions



Source: Kaimal, J. C., Wyngaard, J., Izumi, Y., & Coté, O. R. (1972). Spectral characteristics of surface-layer turbulence. *Quarterly Journal of the Royal Meteorological Society*, *98*(417), 563-589.

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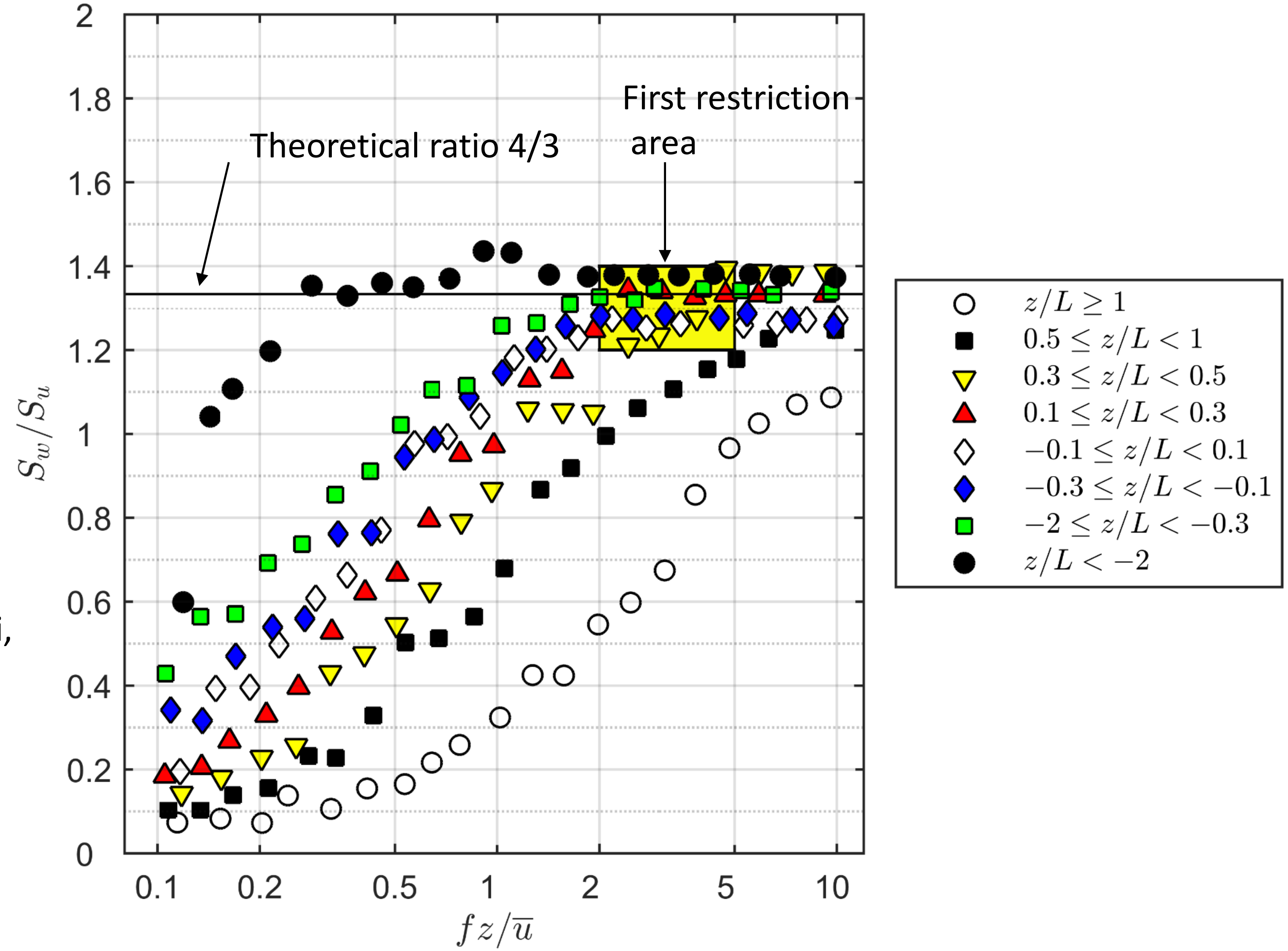

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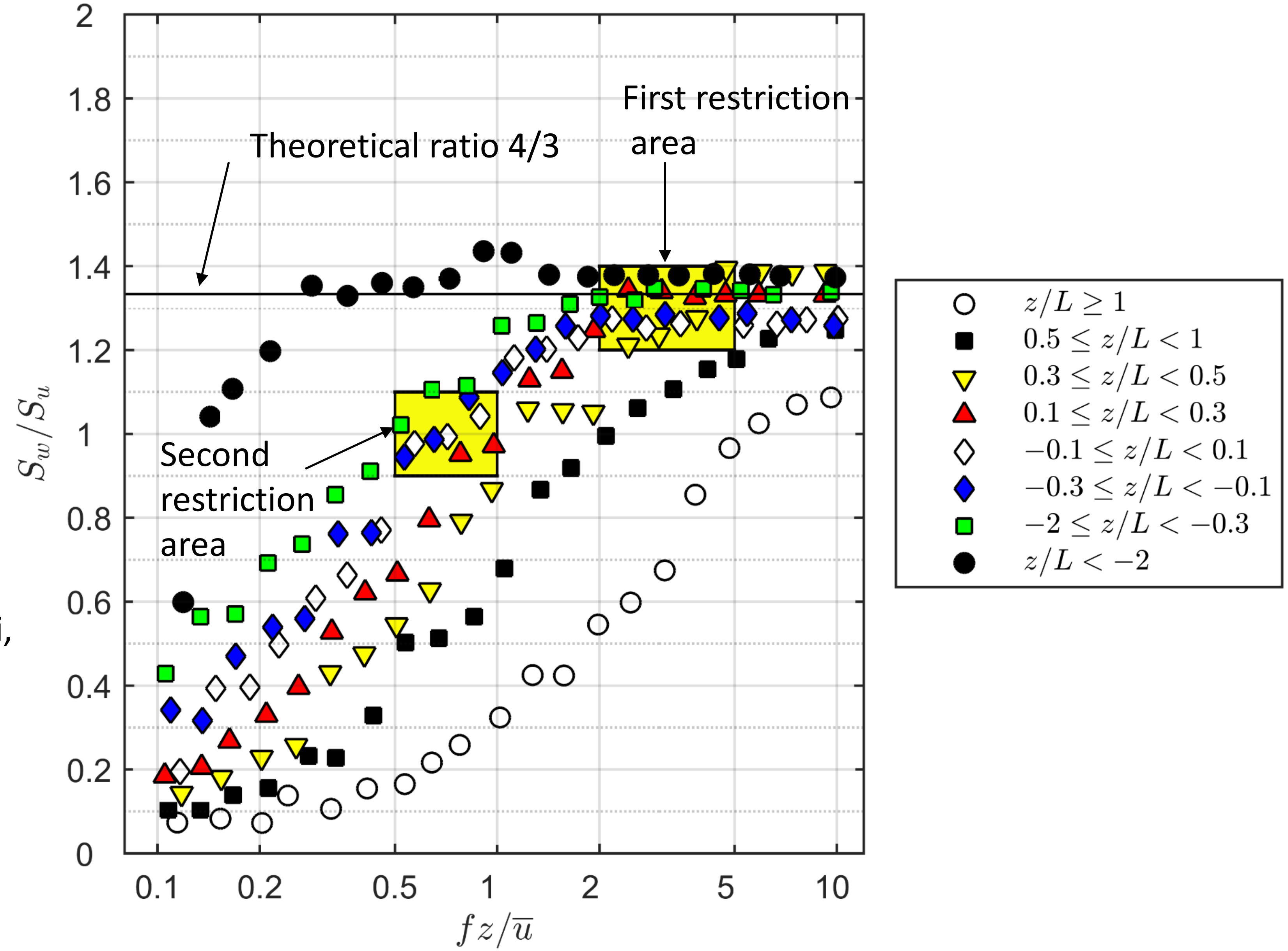
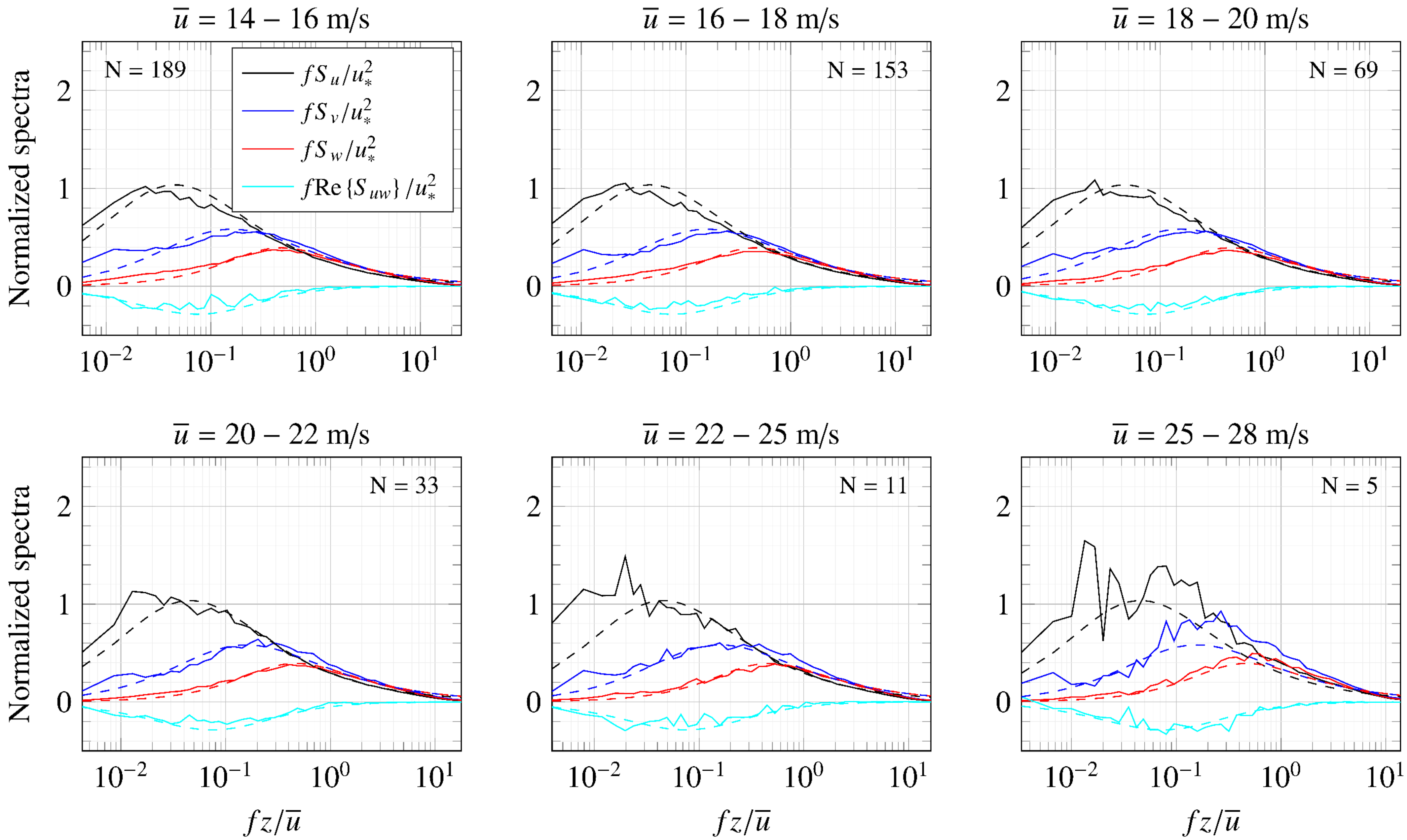


Source: Kaimal, J. C., Wyngaard, J., Izumi, Y., & Coté, O. R. (1972). Spectral characteristics of surface-layer turbulence. *Quarterly Journal of the Royal Meteorological Society*, *98*(417), 563-589.

Measured vs Kaimal spectra



Original Kaimal spectrum
For
along wind component

$$\frac{f\,S_u}{u_*^2} = \frac{a\,n}{(1+b\,n)^{5/3}}$$

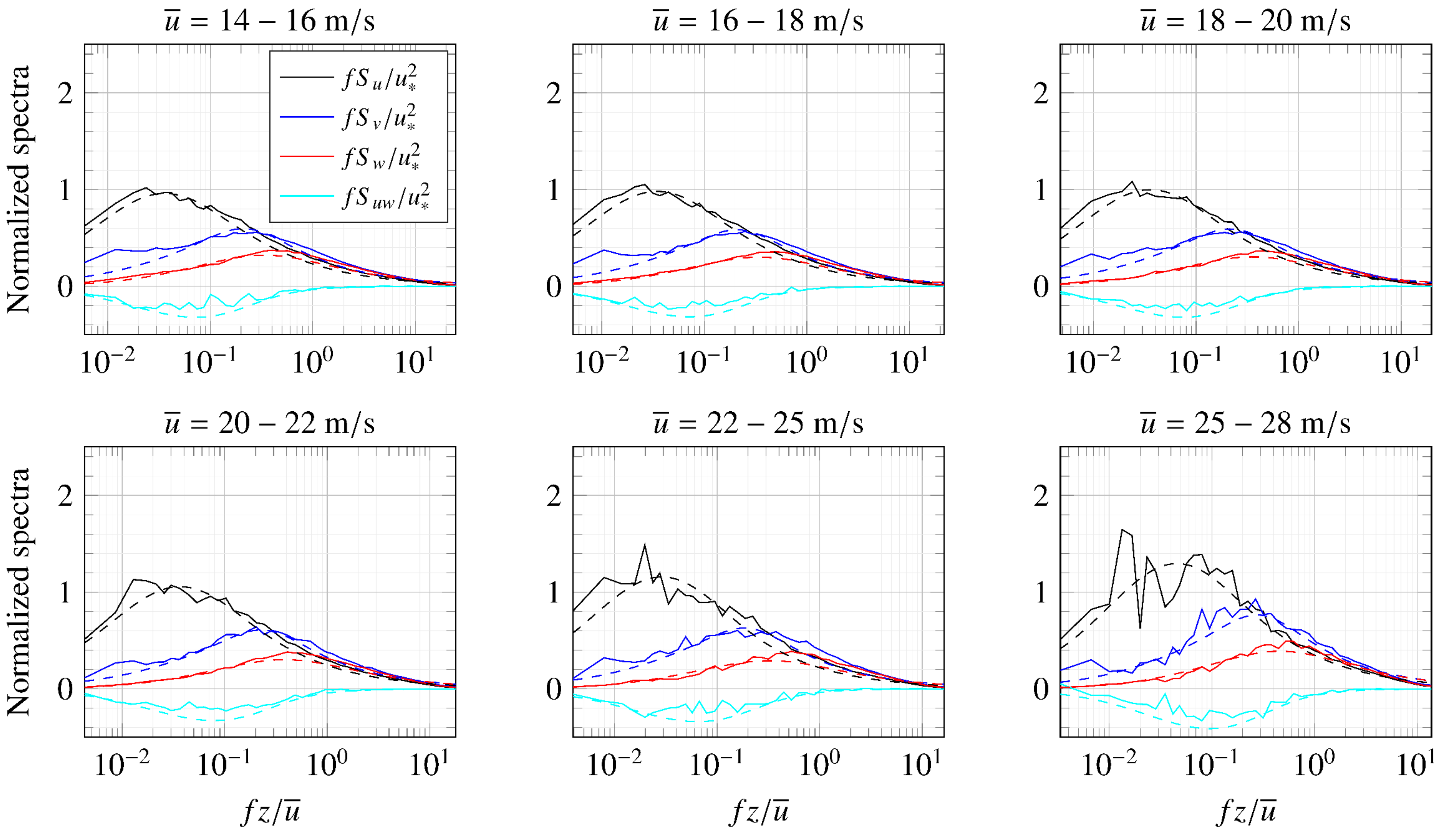
$a = 105$
b = 33

Fitted spectral model
For
along wind component

$$\frac{f\,S_u}{u_*^2} = \frac{a\,n}{(1+b\,n)^{5/3}}$$

$a = 148$
b = 45

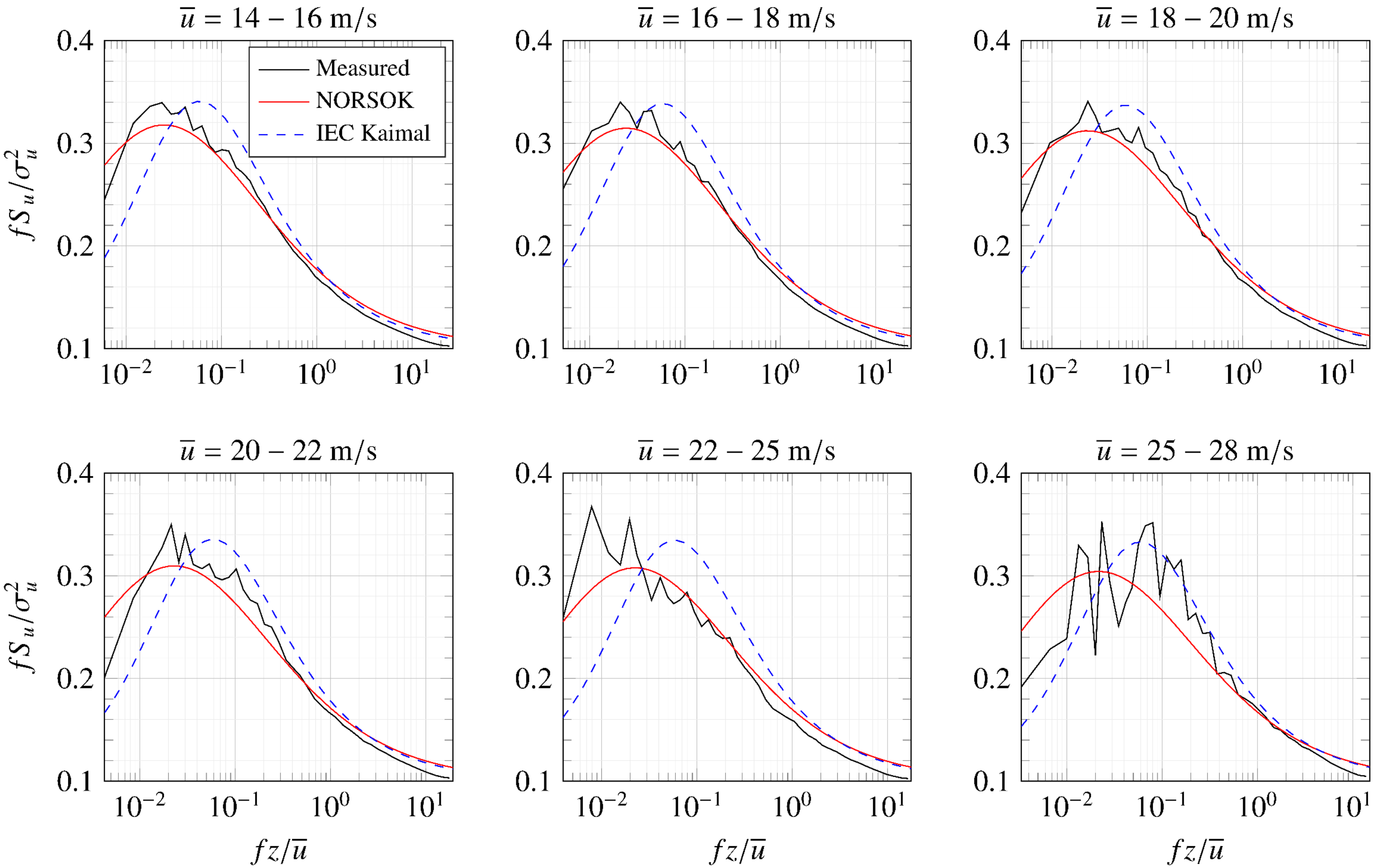
Measured vs fitted Mann spectral model



Fitted parameters:

$\Gamma = 3.7$
$L = 70$ m
$\alpha\epsilon^{2/3} = 0.04\ m^{4/3}s^{-2}$

Measured vs NORSOK vs IEC Kaimal spectra



IEC Kaimal spectrum
For
along wind component

$$\frac{f\,S_u}{\sigma_u^2} = \frac{4\,f_r}{(1+6\,f_r)^{5/3}}$$

$$f_r = \frac{f L_u}{\bar{u}}$$

$$L_u = 8.1\,\Lambda_1$$

$$\Lambda_1 = 42\text{ m (at } z = 80\text{ m)}$$

Modified IEC Kaimal spectrum
For
along wind component

$$\frac{f\,S_u}{\sigma_u^2} = \frac{4\,f_r}{(1+6\,f_r)^{5/3}}$$

$$f_r = \frac{f L_u}{\bar{u}}$$

$$L_u = 8.1\,\Lambda_1$$

$$\Lambda_1 = 73\text{ m (at } z = 80\text{ m)}$$

Conclusions

- 2 year of wind measurement conducted at FINO 1 platform, 80 m above sea level

- Single-point wind spectra were measured and compared to:
    1. Kaimal spectral model
    2. IEC Kaimal model (IEC 61400)
    3. NORSOK standard
    4. Mann spectral model

- Larger energy content at low frequency than predicted

- A good overall agreement with Kaimal spectrum is observed

- > 80 % of wind data detected as “non-neutral” conditions

Questions ?