Field campaign results in urban area

L. Mortarini
E. Ferrero

D. Anfossi
S. Trini Castelli
E. Carretto

R. Richiardone
S. Falabino

University of Piemonte Orientale, Alessandria, Italy

Institute of Atmospheric Sciences and Climate (CNR), Torino, Italy

University of Torino, General Physics Department, Torino Italy

l.mortarini@isac.cnr.it

12th Annual GMU Conference
Atmospheric Transport and Dispersion Modeling

Aims

One year of turbulence measurements (12/1/07 - 4/23/08) and continuous wind data were collected at 3 different levels (5, 9, 25m) inside the Torino (Italy) urban Area.

Study of the turbulence statistics in a urban PBL:

- Evaluation of the principal turbulence characteristics
- Testing of turbulence parametrization (with modelling purposes)
- Focus on Low-Wind conditions

We present a preliminary analysis of the anemometric data from 4/14/07 - 5/1/07.

Campaign Instruments

3 Sonic Anemometer
3 levels: 5, 9, 25 m
f = 20 Hz

Radiometer
Temperature profile up to 1000 m
spatial resolution 50 m
f = 60 GHz

Wind Profiler
Doppler Radar, f =915 MHz
Wind velocity components up to 3000 m

Satellite Images of the sites
Anemometric Mast

Satellite Images of the sites
ARPA instrumentats

Radiometer

Wind-profiler

Satellite Images of the sites

Estimated Parameters

In our preliminary analysis the attention was mainly focused on the turbulence parameters which enter inside the numerical dispersion models.

All the statistics are evaluated considering subsets of 1 hour (7200 data).

Estimated Parameters

In our preliminary analysis the attention was mainly focused on the turbulence parameters which enter inside the numerical dispersion models.

All the statistics are evaluated considering subsets of 1 hour (7200 data).

$$\sigma_i \ , \ S_i \ , \ K_i$$

Estimated Parameters

In our preliminary analysis the attention was mainly focused on the turbulence parameters which enter inside the numerical dispersion models.

All the statistics are evaluated considering subsets of 1 hour (7200 data).

$$\sigma_i \ , \ S_i \ , \ K_i$$

↙

Lagrangian Models

Estimated Parameters

In our preliminary analysis the attention was mainly focused on the turbulence parameters which enter inside the numerical dispersion models.

All the statistics are evaluated considering subsets of 1 hour (7200 data).

$$\sigma_i \ , \ S_i \ , \ K_i$$

Lagrangian Models

High-Order Closure Models

Estimated Parameters

In our preliminary analysis the attention was mainly focused on the turbulence parameters which enter inside the numerical dispersion models.

All the statistics are evaluated considering subsets of 1 hour (7200 data).

$$\sigma_i \ , \ S_i \ , \ K_i$$

$$u_* \ , \ w_* \ , \ z_i \ , \ \theta_* \ , \ L$$

Lagrangian Models

High-Order Closure Models

Estimated Parameters

In our preliminary analysis the attention was mainly focused on the turbulence parameters which enter inside the numerical dispersion models.

All the statistics are evaluated considering subsets of 1 hour (7200 data).

$$\sigma_i \ , \ S_i \ , \ K_i$$

Lagrangian Models

High-Order Closure Models

$$u_* \ , \ w_* \ , \ z_i \ , \ \theta_* \ , \ L$$

To test the turbulent parametrizations

Estimated Parameters

In our preliminary analysis the attention was mainly focused on the turbulence parameters which enter inside the numerical dispersion models.

All the statistics are evaluated considering subsets of 1 hour (7200 data).

$\sigma_i \ , \ S_i \ , \ K_i$

Lagrangian Models

High-Order Closure Models

$u_* \ , \ w_* \ , \ z_i \ , \ \theta_* \ , \ L$

All the turbulent fluxes are evaluated at 5 m.

To test the turbulent parametrizations

Estimated Parameters

In our preliminary analysis the attention was mainly focused on the turbulence parameters which enter inside the numerical dispersion models.

All the statistics are evaluated considering subsets of 1 hour (7200 data).

We used our data to test two turbulence parametrizations:

Hanna (1982)
Degrazia et al. (2002)

Turbulence Parametrizations: Hanna (1982)

Unstable Case

$$\sigma_u = \sigma_v = u_* \left(12 + \frac{1}{2}\frac{z_i}{|L|}\right)^{1/3}$$

$$\frac{z}{z_i} < 0.03 \qquad \sigma_w = 0.96 w_* \left(3\frac{z}{z_i} - \frac{L}{z_i}\right)^{1/3}$$

$$0.03 < \frac{z}{z_i} < 0.4 \qquad \sigma_w = w_* min\left[0.96\left(3\frac{z}{z_i} - \frac{L}{z_i}\right)^{1/3}, 0.763\left(\frac{z}{z_i}\right)^{0.175}\right]$$

$$0.4 < \frac{z}{z_i} < 0.96 \qquad \sigma_w = 0.722 w_* \left(1 - \frac{z}{z_i}\right)^{0.207}$$

$$0.96 < \frac{z}{z_i} < 1 \qquad \sigma_w = 0.37 w_*$$

$$T_{Lu} = T_{Lv} = 0.15\frac{z_i}{\sigma_w}$$

$$T_{Lw} = 0.1\frac{z_i}{\sigma_w}\frac{1}{0.55 + 0.38\frac{z-z_0}{L}} \qquad \frac{z}{z_i} < 0.1 \ \wedge \ \frac{z-z_0}{L} < 1$$

$$T_{Lw} = 0.59\frac{z_i}{\sigma_w} \qquad \frac{z}{z_i} < 0.1 \ \wedge \ \frac{z-z_0}{L} > 1$$

$$T_{Lw} = 0.15\frac{z_i}{\sigma_w}\left[1 - exp\left(-5\frac{z}{z_i}\right)\right] \qquad \frac{z}{z_i} > 0.1$$

Turbulence Parametrizations: Hanna (1982)

Stable Case

$$\sigma_u = 2u_* \left(1 - \frac{z}{h}\right)$$

$$\sigma_w = \sigma_v = 1.3u_* \left(1 - \frac{z}{h}\right)$$

$$T_{Lu} = 0.15 \frac{h}{\sigma_u} \left(\frac{z}{h}\right)^{0.5}$$

$$T_{Lv} = 0.07 \frac{h}{\sigma_v} \left(\frac{z}{h}\right)^{0.5}$$

$$T_{Lw} = 0.10 \frac{h}{\sigma_w} \left(\frac{z}{h}\right)^{0.8}$$

Neutral Case

$$\sigma_u = 2u_* exp \left(-\frac{3f_c z}{u_*}\right)$$

$$\sigma_v = \sigma_w = 1.3u_* exp \left(-\frac{2f_c z}{u_*}\right)$$

$$T_{Lu} = T_{Lv} = T_{Lw} = \frac{0.5\frac{z}{\sigma_w}}{1 + 15\frac{2f_c z}{u_*}}$$

Turbulence Parametrizations: Degrazia et al. (2002)

$$T_{Li} = \frac{li}{\sigma_i} = \frac{z}{\sqrt{c_i}} \left\{ \frac{0.14 \left(\frac{-\bar{L} z_i}{z_i - L} \right)^{1/2}}{\left[(f_m^c)_i^c \right]^{2/3} w_* \left(\psi_{\epsilon \frac{z}{z_i}} \right)^{1/3}} + \frac{0.059}{\left[(f_m^c)_i^{n+s} \right]^{2/3} \left(\phi_\epsilon^{n+s} \right)^{1/3} u_*} \right\}$$

$$\frac{-\bar{L}}{z_i} = 0.01 \qquad c_i = \alpha_i \left(0.5 \pm 0.05\right) \left(2\pi\kappa\right)^{-2/3} \qquad \kappa = 0.4$$

$$\begin{cases} \alpha_u = 1 \\ \alpha_v = \frac{4}{3} \\ \alpha_v = \frac{4}{3} \end{cases}$$

$$\sigma_i^2 = \sigma_{ib}^2 + \sigma_{is}^2$$

$$\sigma_{ib}^2 = \int_0^\infty S_{ib}^E(n)dn = \frac{1.06 c_i \psi_\epsilon^{2/3} w_*^2 \left(\frac{z}{z_i} \right)^{2/3}}{\left[(f_m^*)_i^c \right]^{2/3}}$$

$$\sigma_{is}^2 = \int_0^\infty S_{is}^E(n)dn = \frac{2.32 c_i \phi_\epsilon^{2/3} w_*^2}{\left[(f_m^*)_i^{n+s} \right]^{2/3}}$$

Turbulence Parametrizations: Degrazia et al. (2002)

CBL

$$\psi_\epsilon^{2/3} \approx 0.75$$

$$(f_m^*)_i^c = \frac{z}{\lambda_{mi}}$$

$$\lambda_{mu} = \lambda_{mv} = 1.5 z_i$$

$$\lambda_{mw} = 1.8 z_i \left[1 - exp\left(-4\frac{z}{z_i}\right) - 0.0003 exp\left(-8\frac{z}{z_i}\right)\right]$$

$$(f_m^*)_i^c = \frac{z}{B_i z_i}$$

$$B_u = B_v = 1.5$$

$$B_w = 1.8\left[1 - exp\left(-4\frac{z}{z_i}\right) - 0.0003 exp\left(-8\frac{z}{z_i}\right)\right]$$

STABLE or NEUTRAL PBL

$$\phi_\epsilon^{n+s} = \phi_\epsilon^n\left(1 + 3.7\frac{z}{\Lambda}\right)$$

$$\phi_\epsilon^n = 1.25 \qquad \Lambda = L\left(1 - \frac{z}{h}\right)^{1.5\alpha_1 - \alpha_2}$$

$\alpha_1 = 1.5 \quad \alpha_2 = 1.0$ Stable with shear

$$u_*^2 = (u_*^2)_0\left(1 - \frac{z}{h}\right)^{\alpha_1}$$

$\alpha_1 = 1.7$ Neutral

$$(f_m^*)_i^{n+s} = (f_m^*)_{is}^n\left(1 + 0.03 a_1\frac{f_c z}{(u_*^2)_0} + 3.7\frac{z}{\Lambda}\right)$$

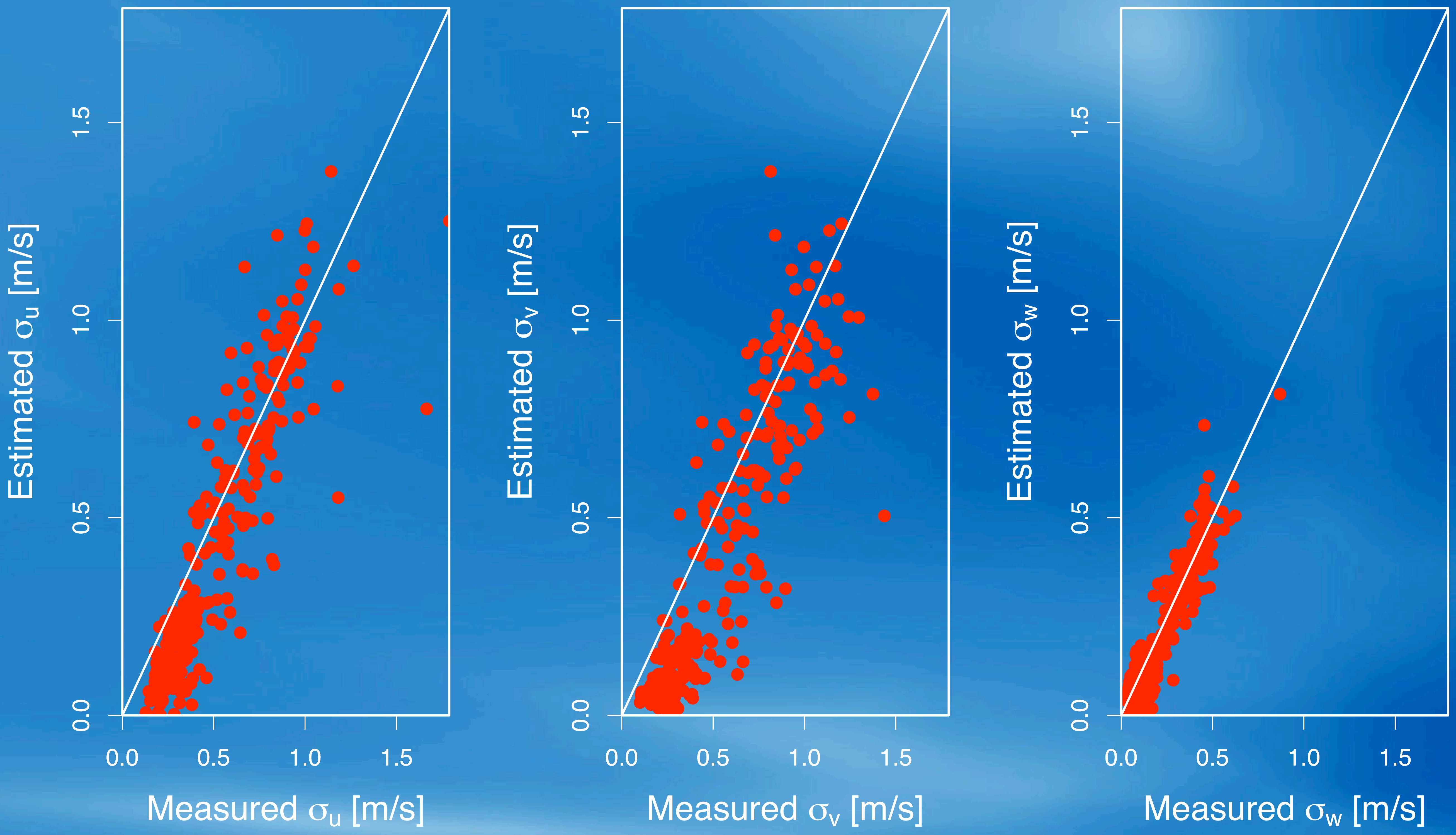
$$(f_m^*)_{us}^n = 0.045 \quad (f_m^*)_{vs}^n = 0.16 \quad (f_m^*)_{ws}^n = 0.16$$

$$a_u = 3889 \qquad a_v = 1094 \qquad a_w = 500$$

Sorbjan (1989), Hanna (1968, 1981), Wyngaard et al. (1974), Stull (1988), Kaimal et al. (1976), Caughey (1982), Anfossi and Degrazia (1998)

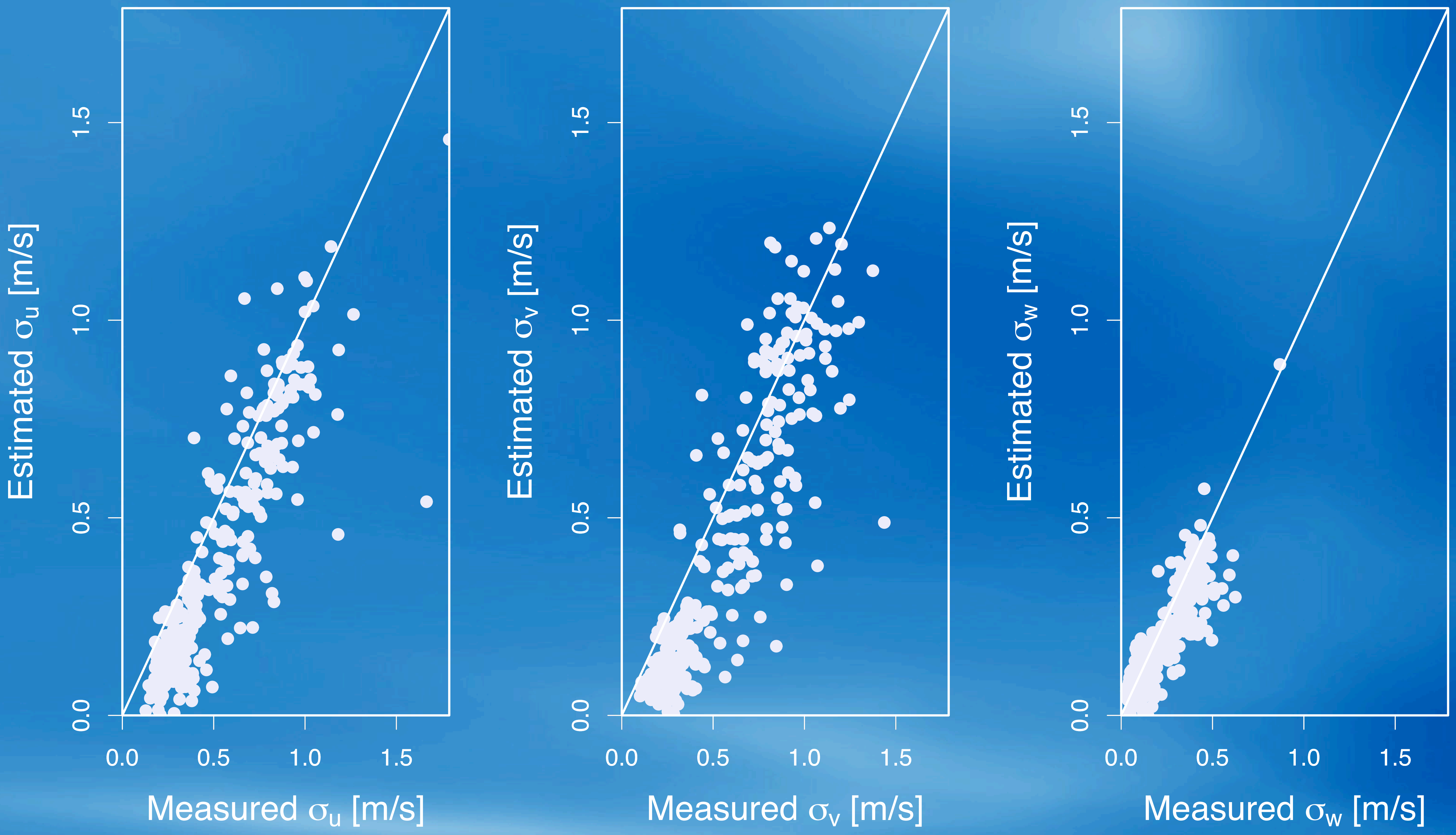
Standard Deviation (5 m)

Hanna (1982)

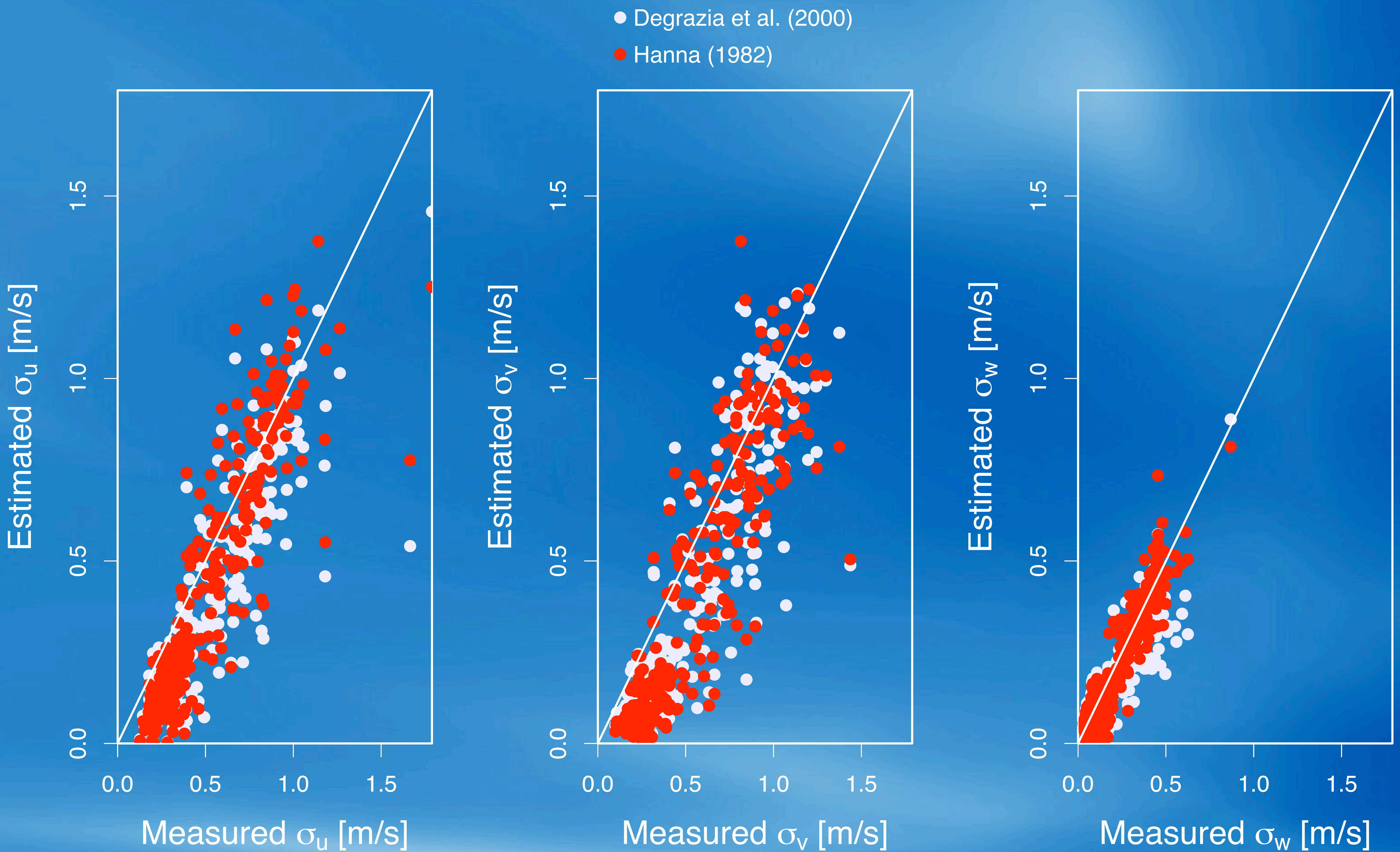


Standard Deviation (5 m)

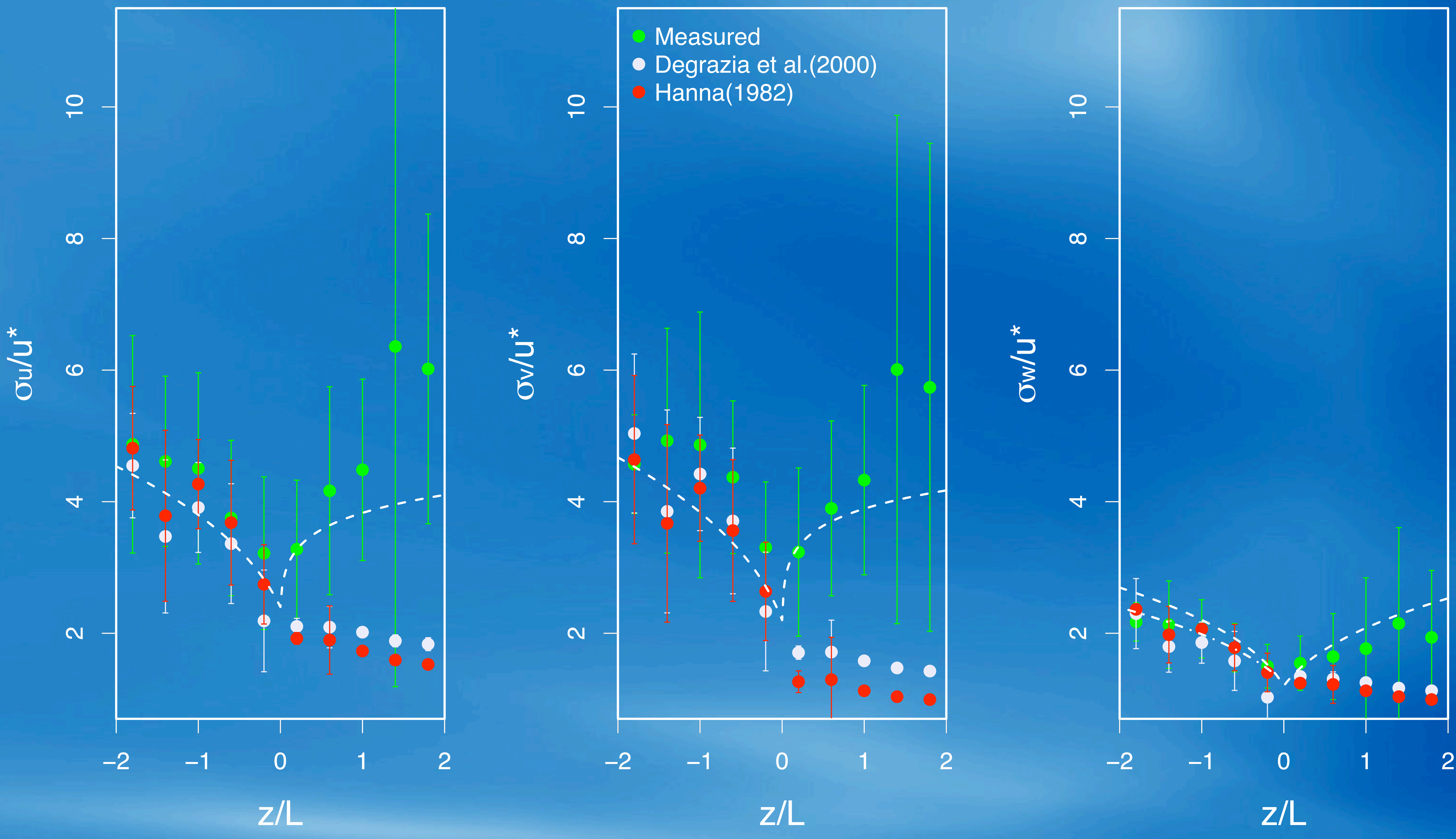
Degrazia et al. (2000)

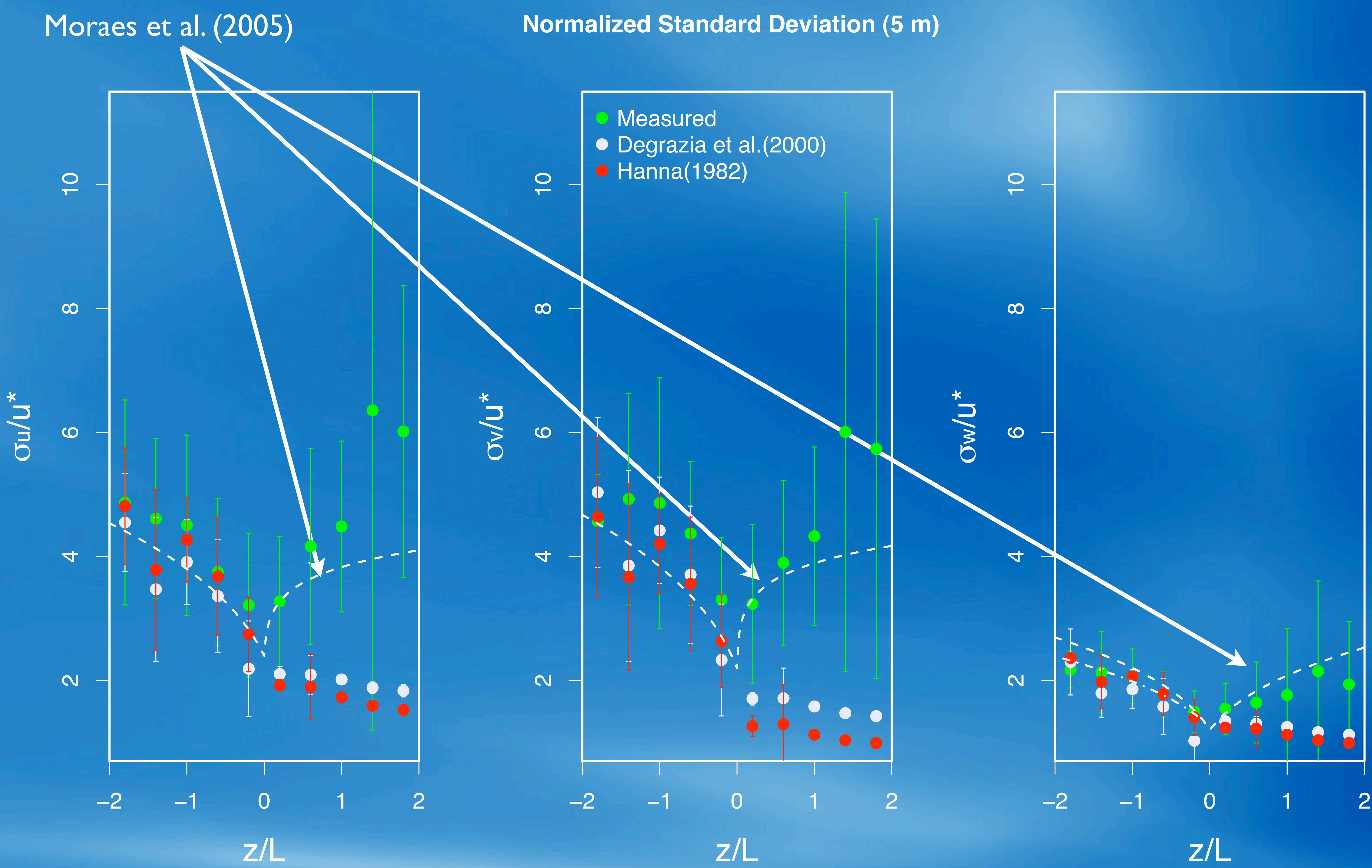


Standard Deviation (5 m)

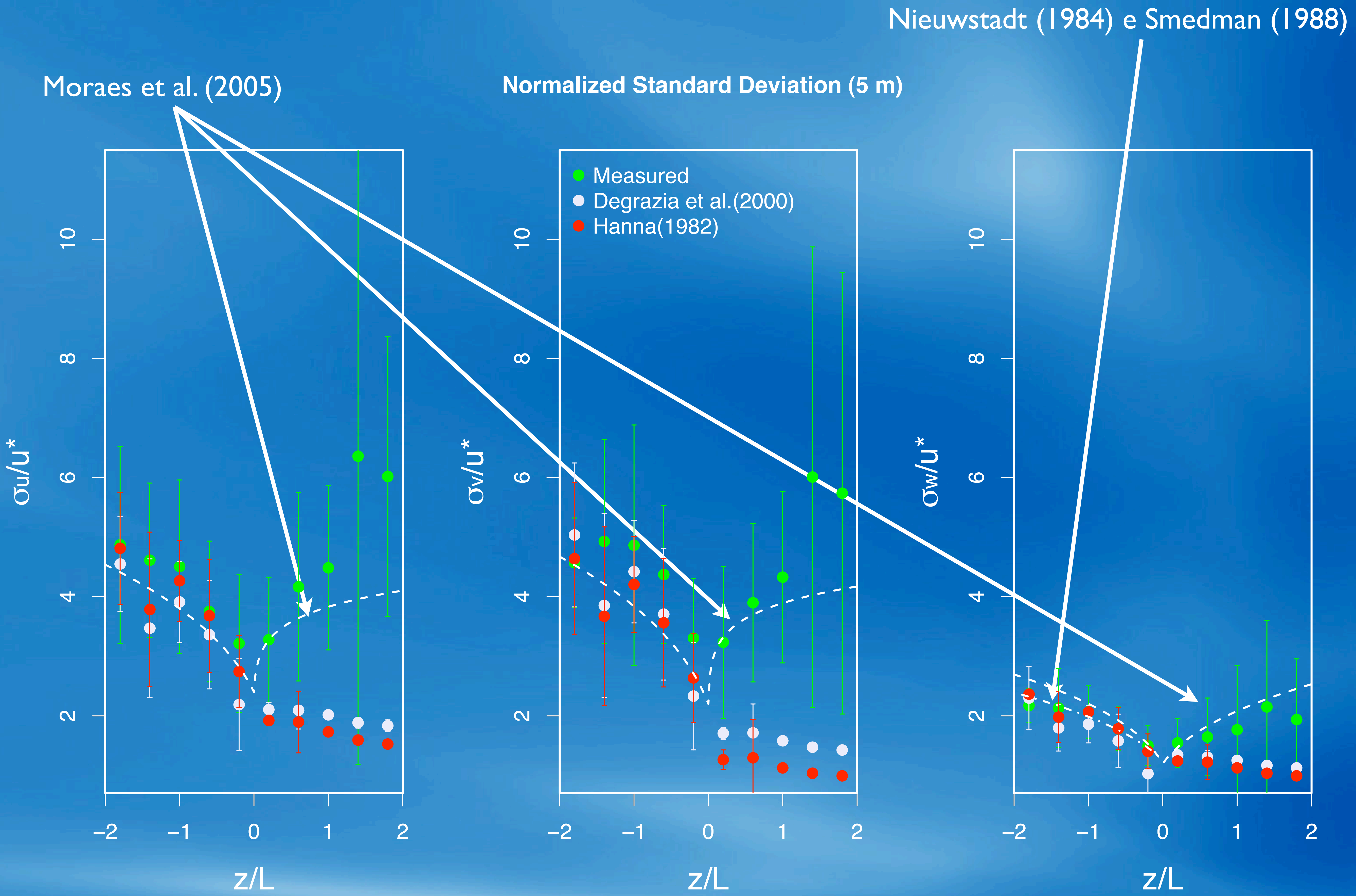


Normalized Standard Deviation (5 m)



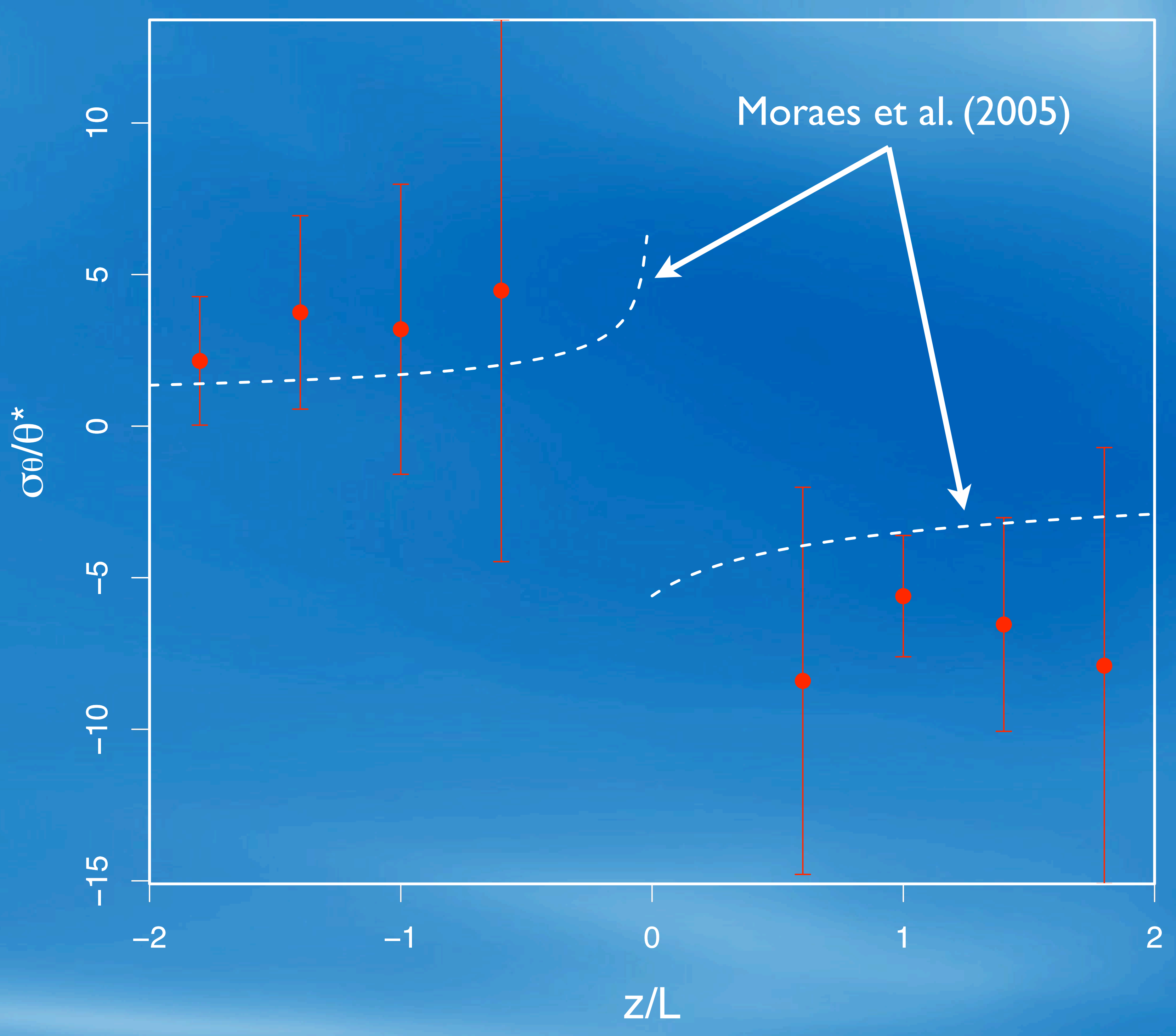


Moraes et al. (2005)
Normalized Standard Deviation (5 m)
Measured
Degrazia et al.(2000)
Hanna(1982)
σu/u*
σv/u*
σw/u*
z/L
z/L
z/L



12th Annual GMU Conference

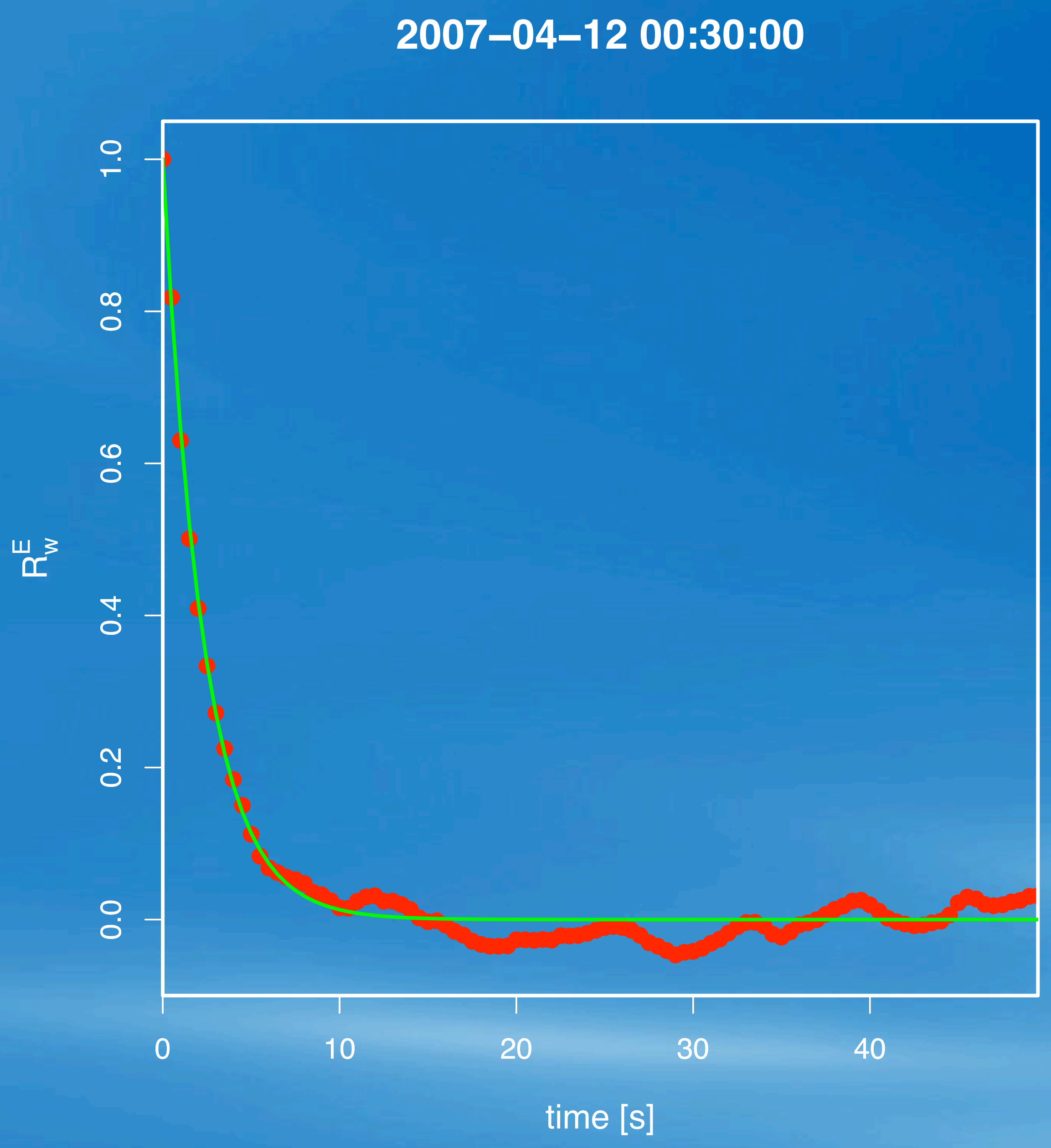
Normalized Standard Deviation (5 m)

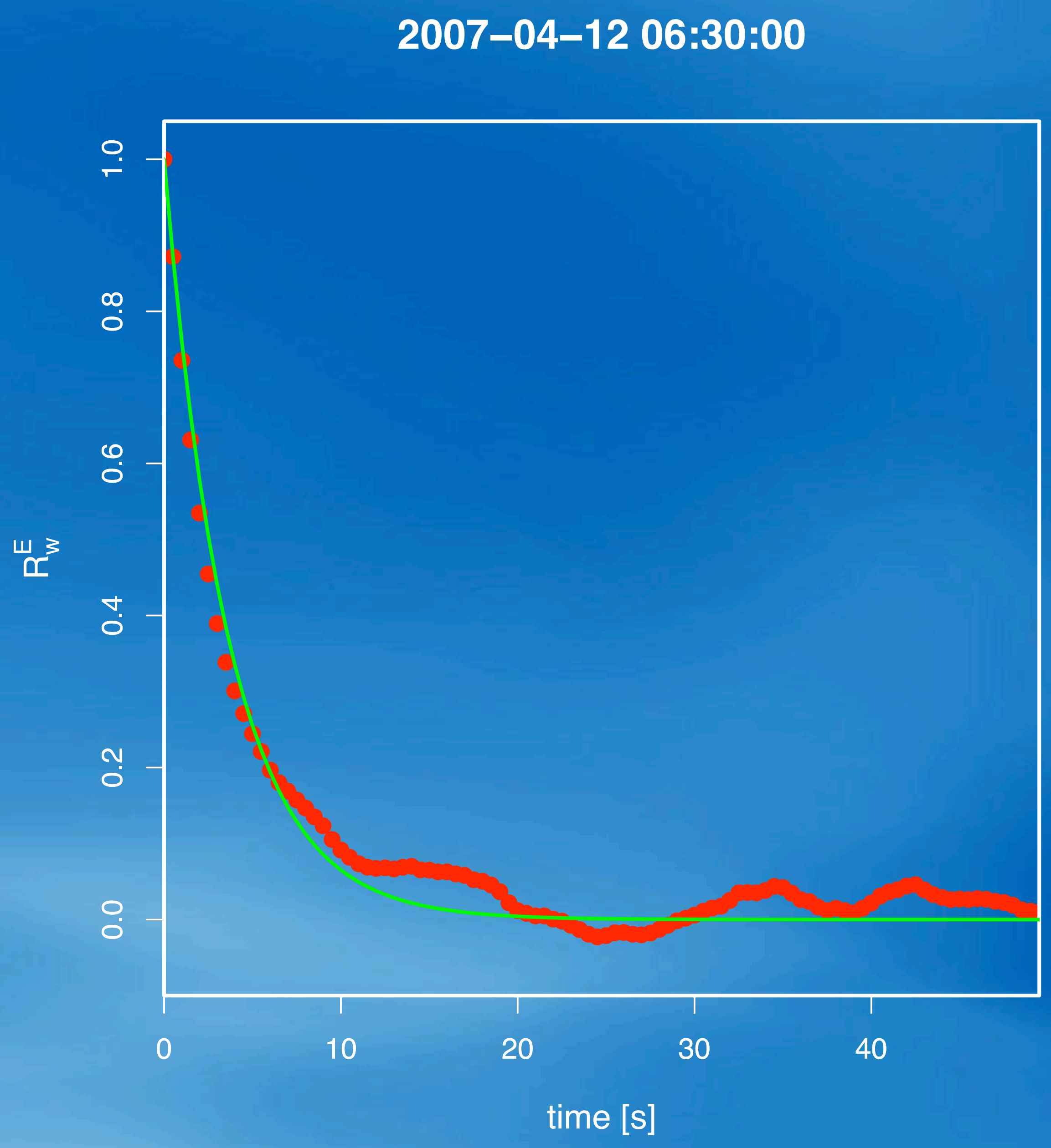


Eulerian Time-Scale

Eulerian Auto-Correlation Function: $R_i^E = \frac{\langle u_i(t)u_i(t+\tau)\rangle}{\sigma_{ui}^2(t)}$

Exponential Case

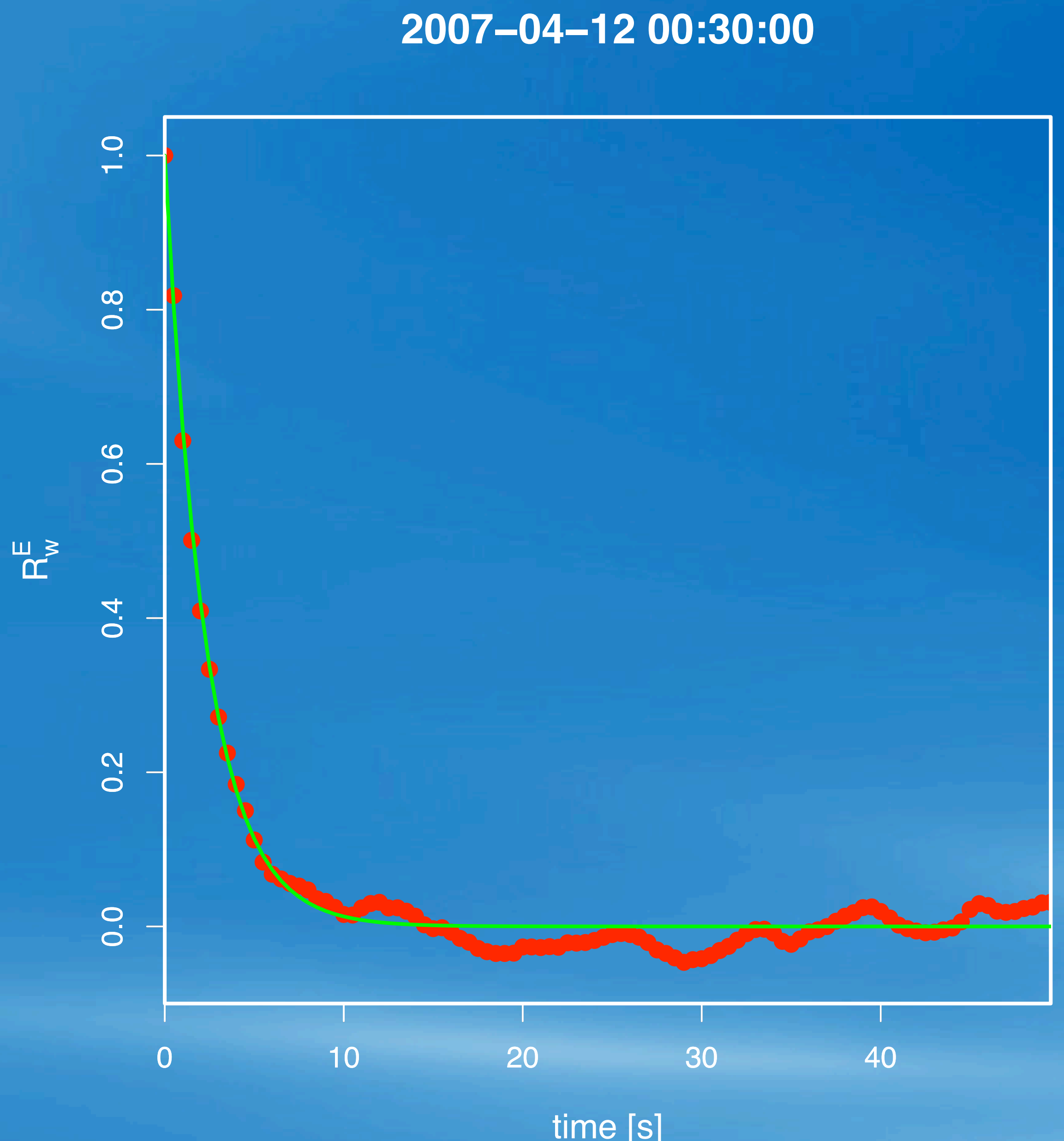




Eulerian Time-Scale

Eulerian Auto-Correlation Function: $$R_i^E = \frac{\langle u_i(t) u_i(t+\tau) \rangle}{\sigma_{ui}^2(t)}$$

Exponential Case



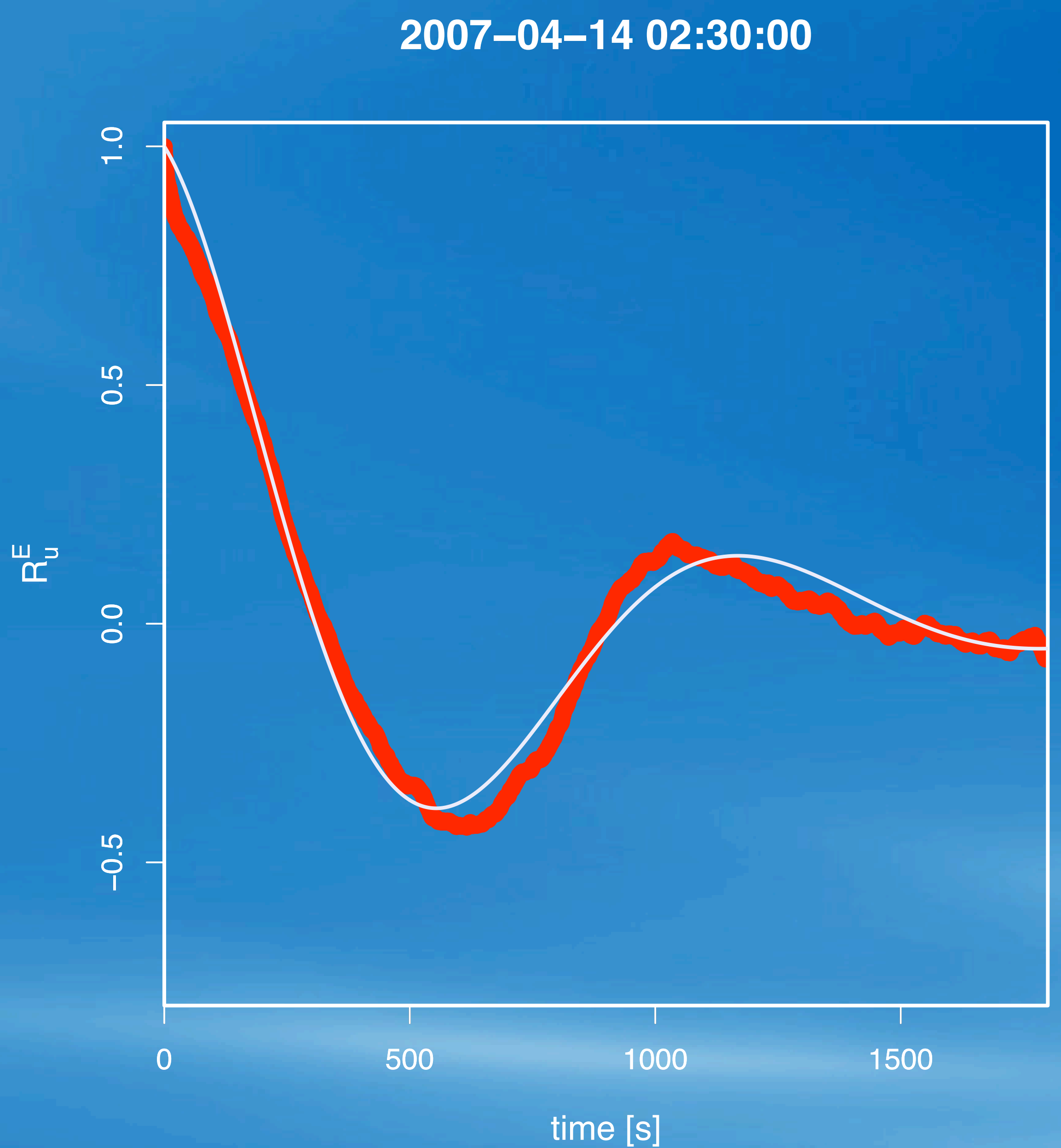
$$R_w^E(\tau) = e^{-\frac{\tau}{T_E}}$$

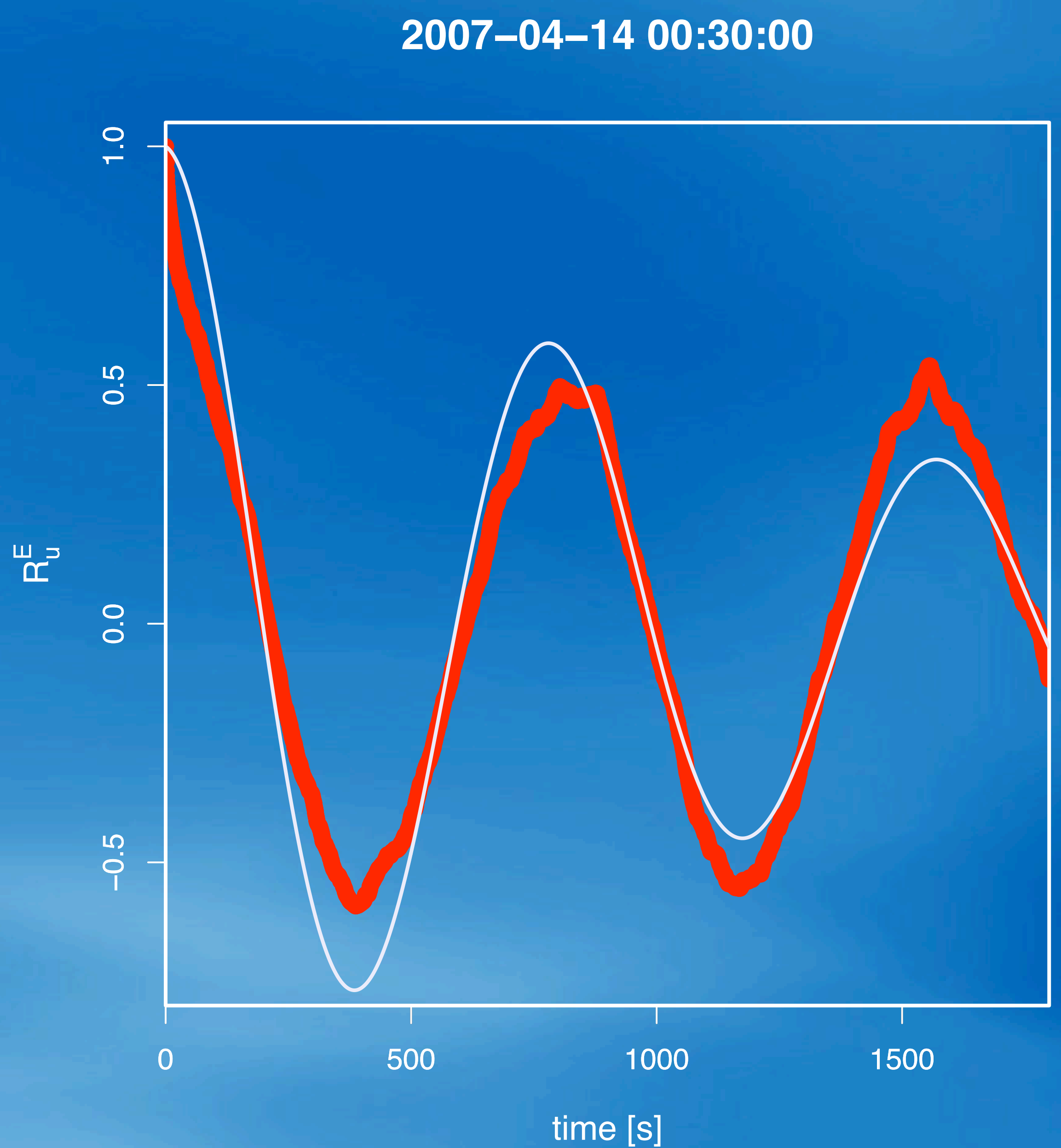
$$R_w^E(T_E) = e^{-1}$$

Eulerian Time-Scale

Eulerian Auto-Correlation Function: $$R_i^E = \frac{\langle u_i(t)u_i(t+\tau)\rangle}{\sigma_{ui}^2(t)}$$

Low-Wind Case

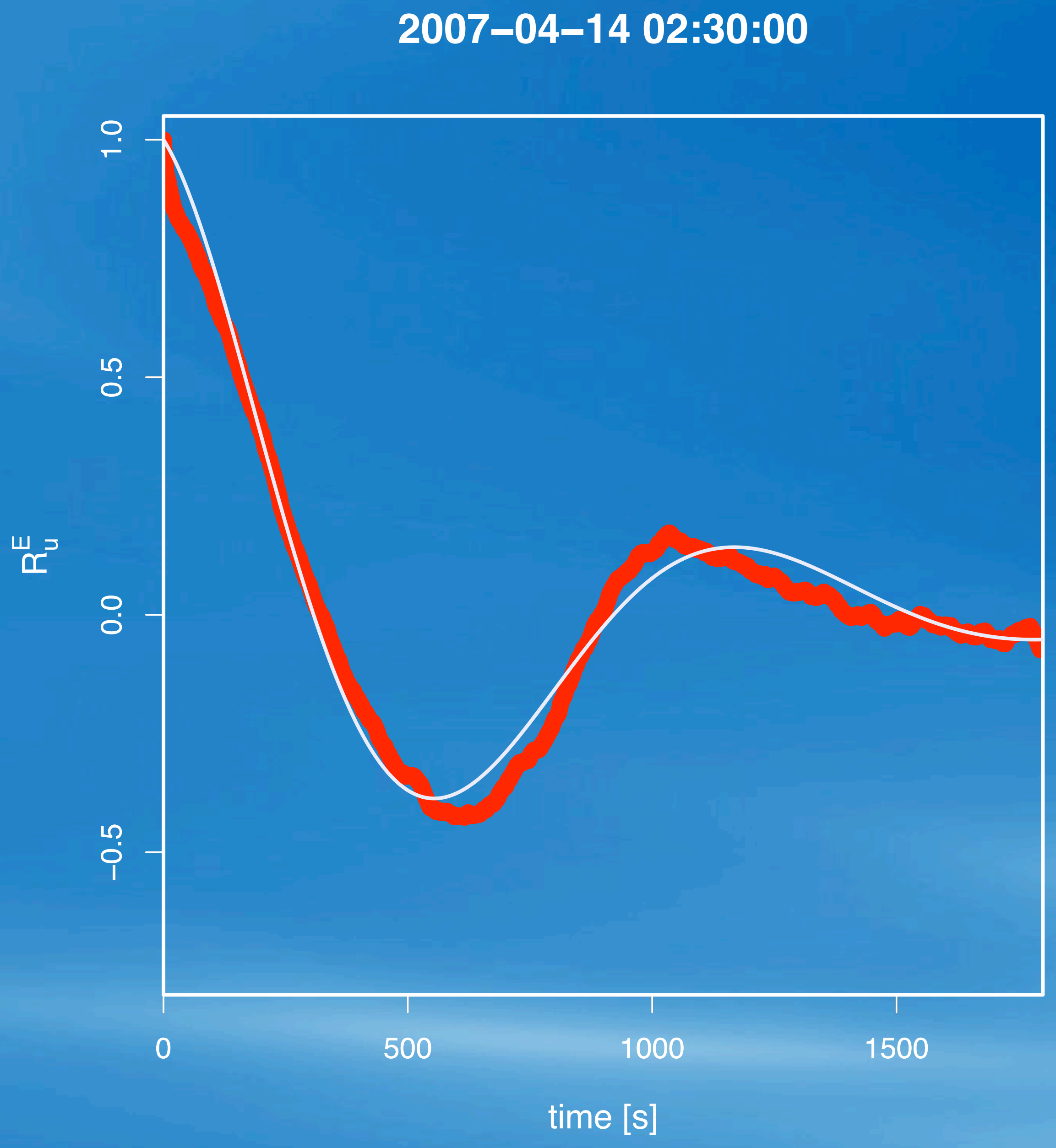




Eulerian Time-Scale

Eulerian Auto-Correlation Function: $R_i^E = \frac{\langle u_i(t) u_i(t+\tau) \rangle}{\sigma_{ui}^2(t)}$

Low-Wind Case



$$R_w^E(\tau) = e^{-p\tau} cos\,(q\tau)$$

$$T_E = \int_0^\infty R_w^E(\tau) = \frac{p}{p^2 + q^2}$$

Anfossi et al. (2005)

Lagrangian Time-Scale

$$\frac{T_i^L}{T_i^E} = \beta_i$$

Hay and Pasquill (1959)

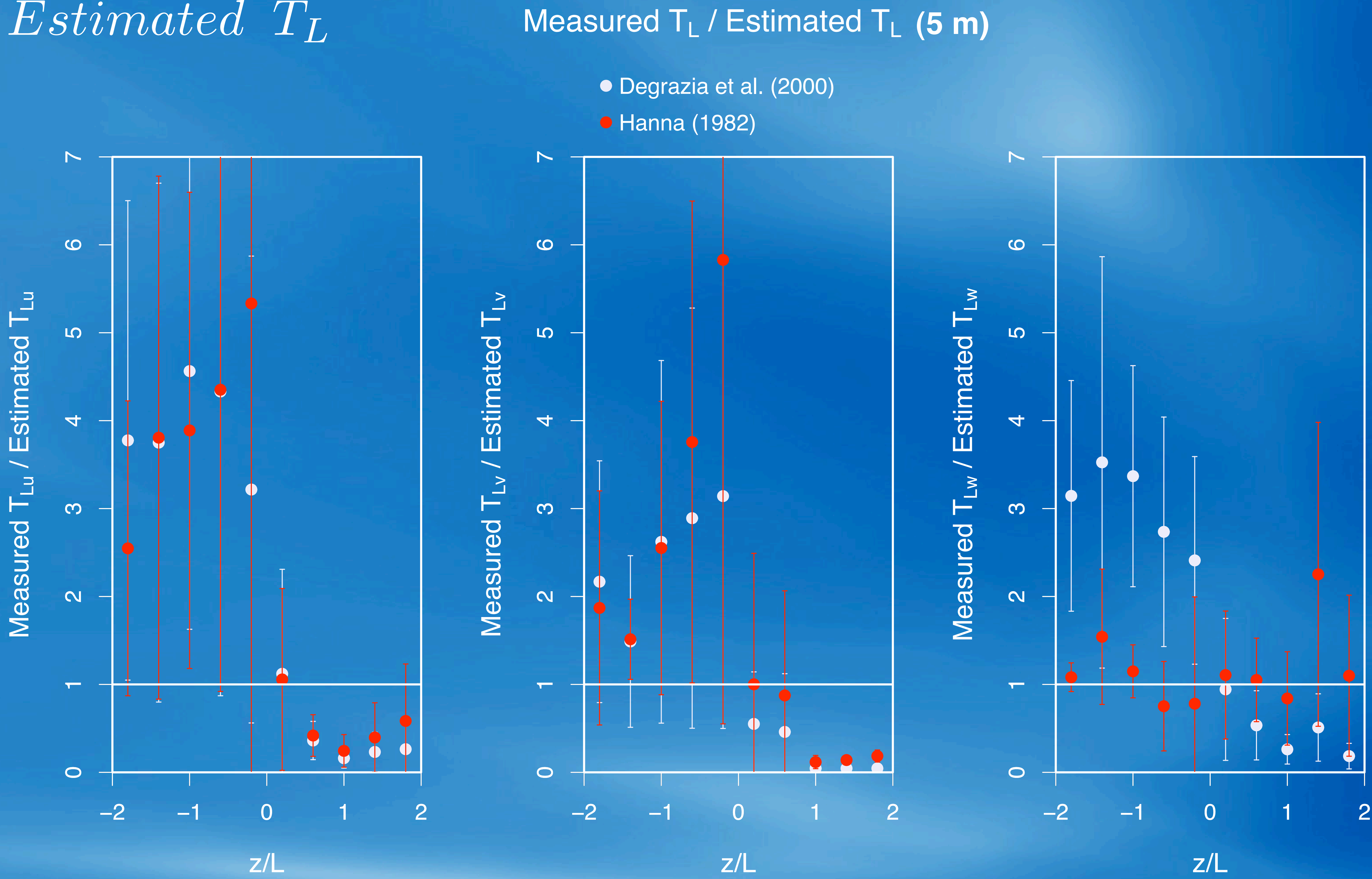
$$\beta_i = d\frac{\langle U \rangle}{\sigma_i}$$

Hanna (1981)

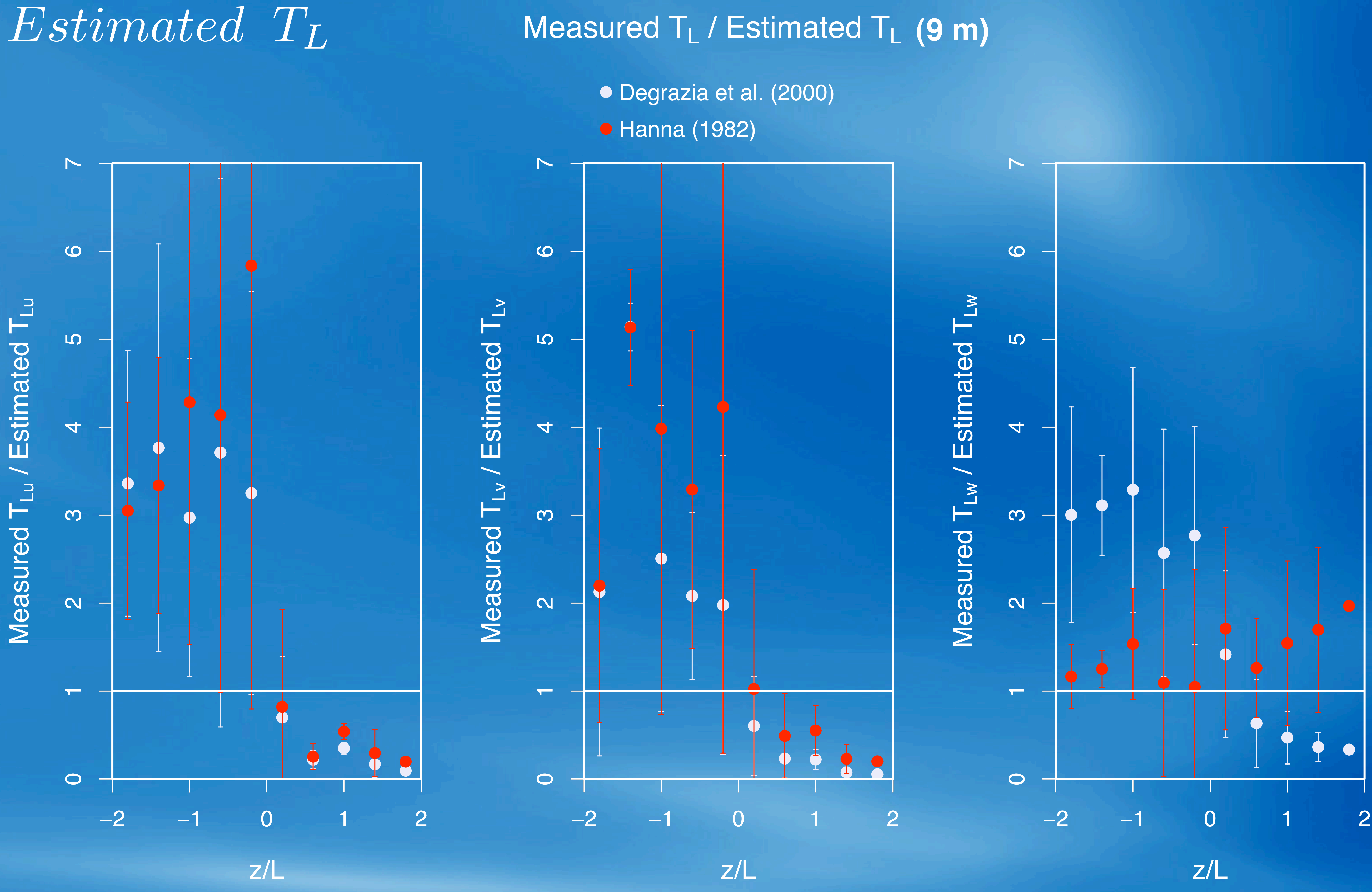
$$d = 0.55$$

Degrazia and Anfossi (1998)

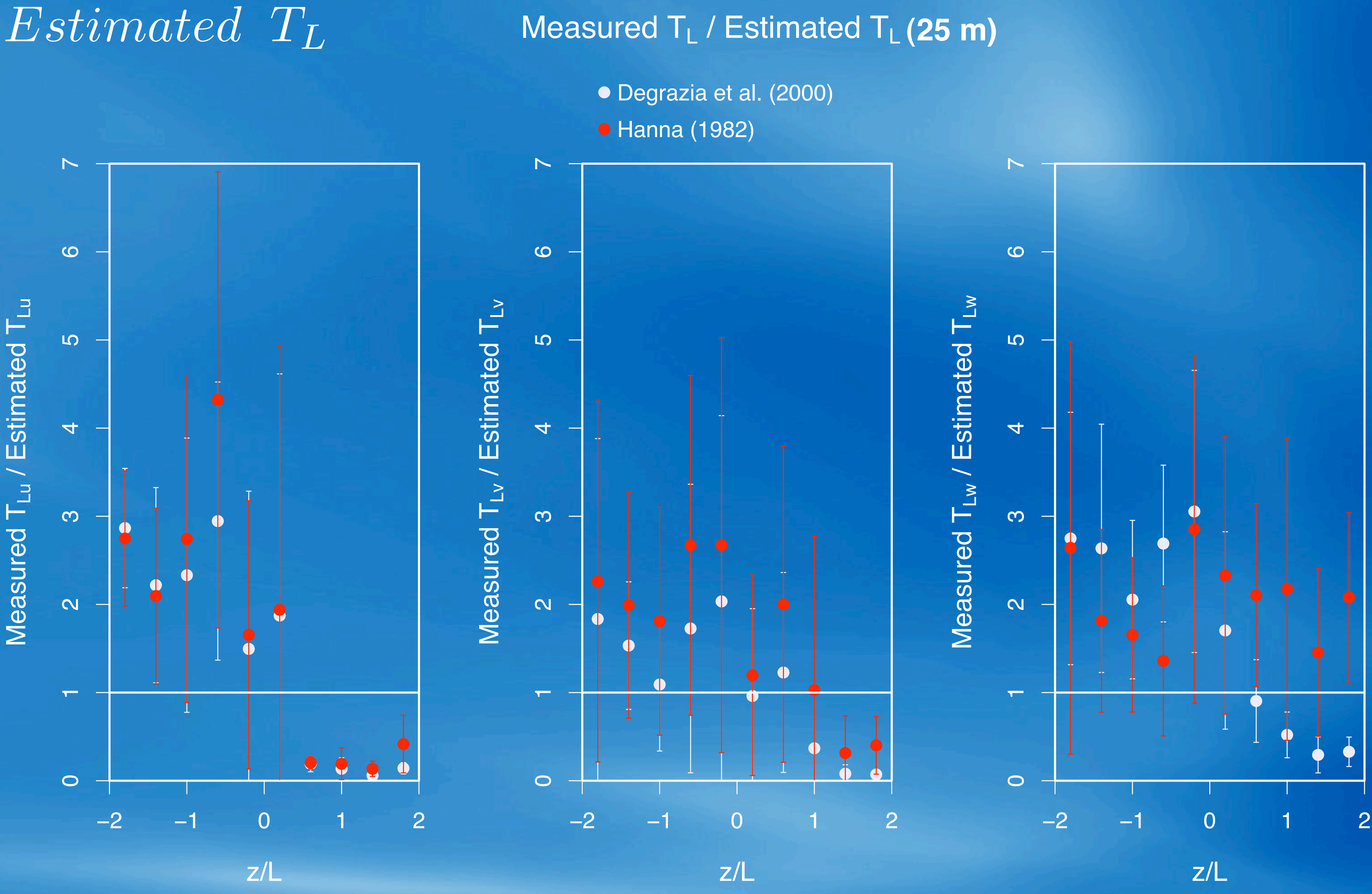
$$\frac{Measured\ T_L}{Estimated\ T_L}$$



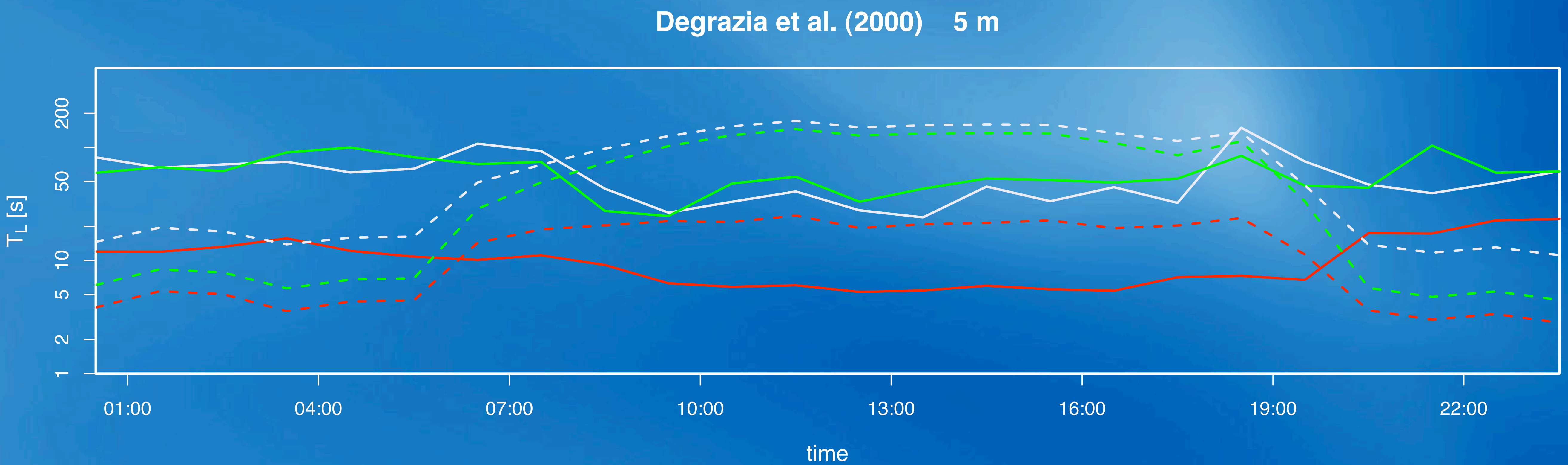
$$\frac{Measured\ T_L}{Estimated\ T_L}$$

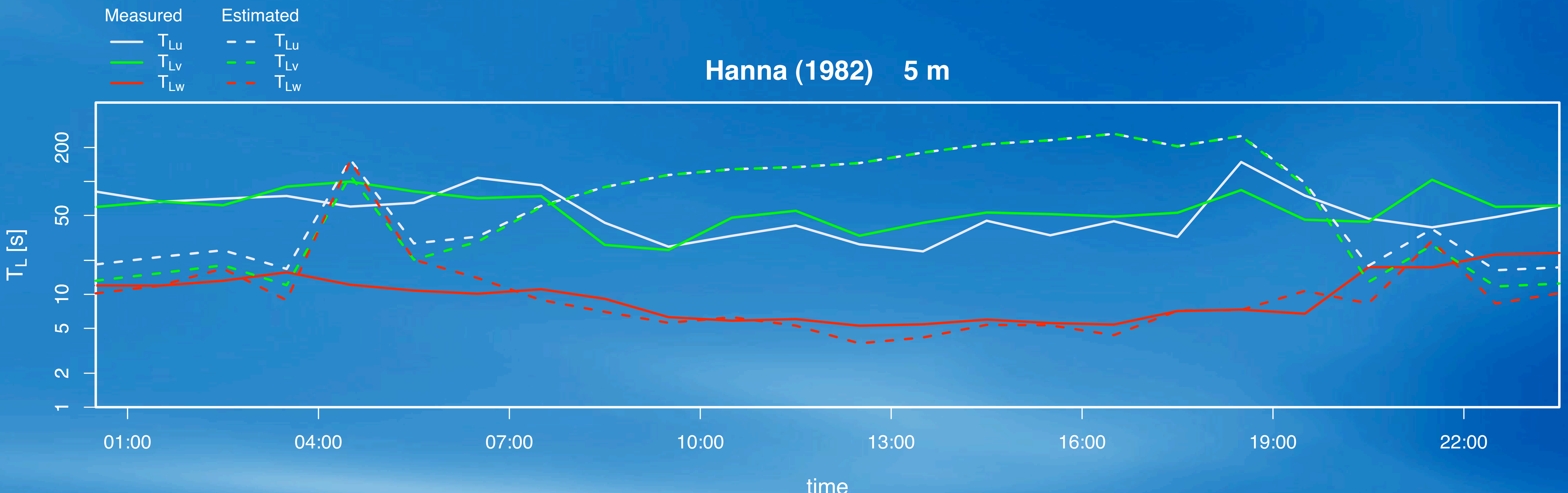


$$\frac{Measured\ T_L}{Estimated\ T_L}$$

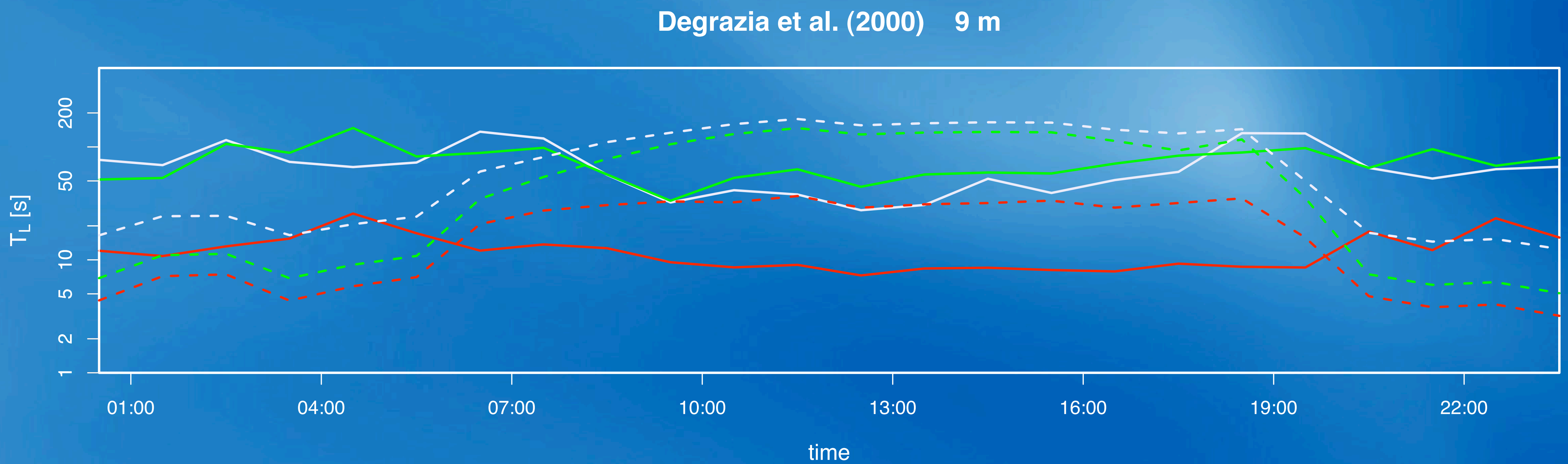


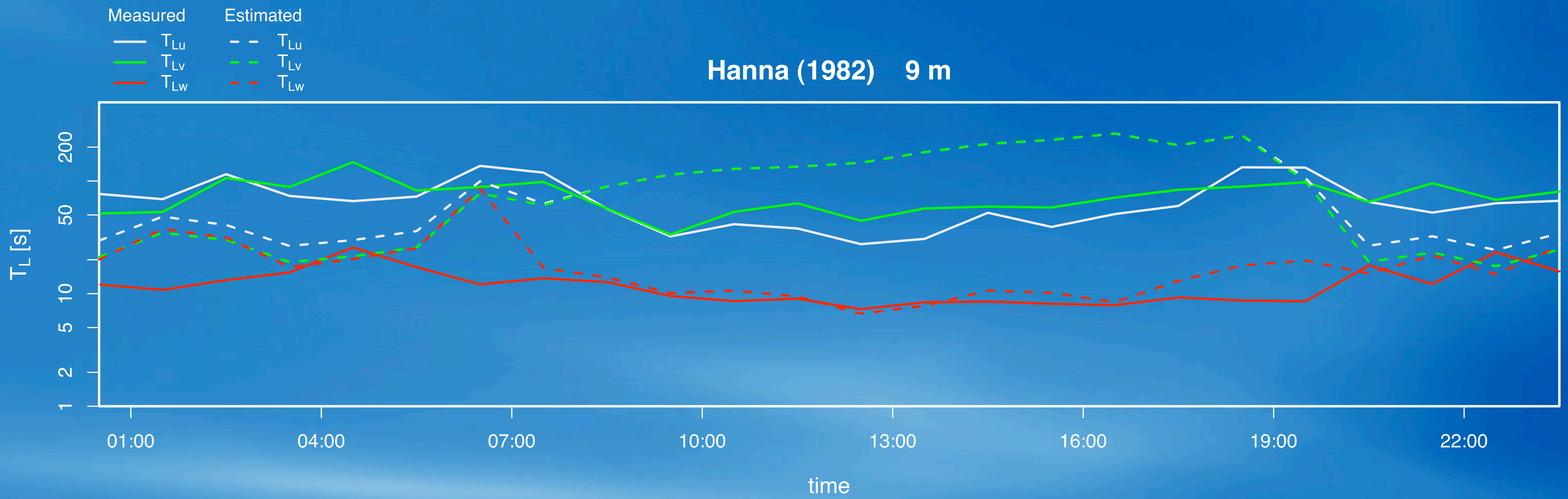
Lagrangian Time-Scale (5 m)



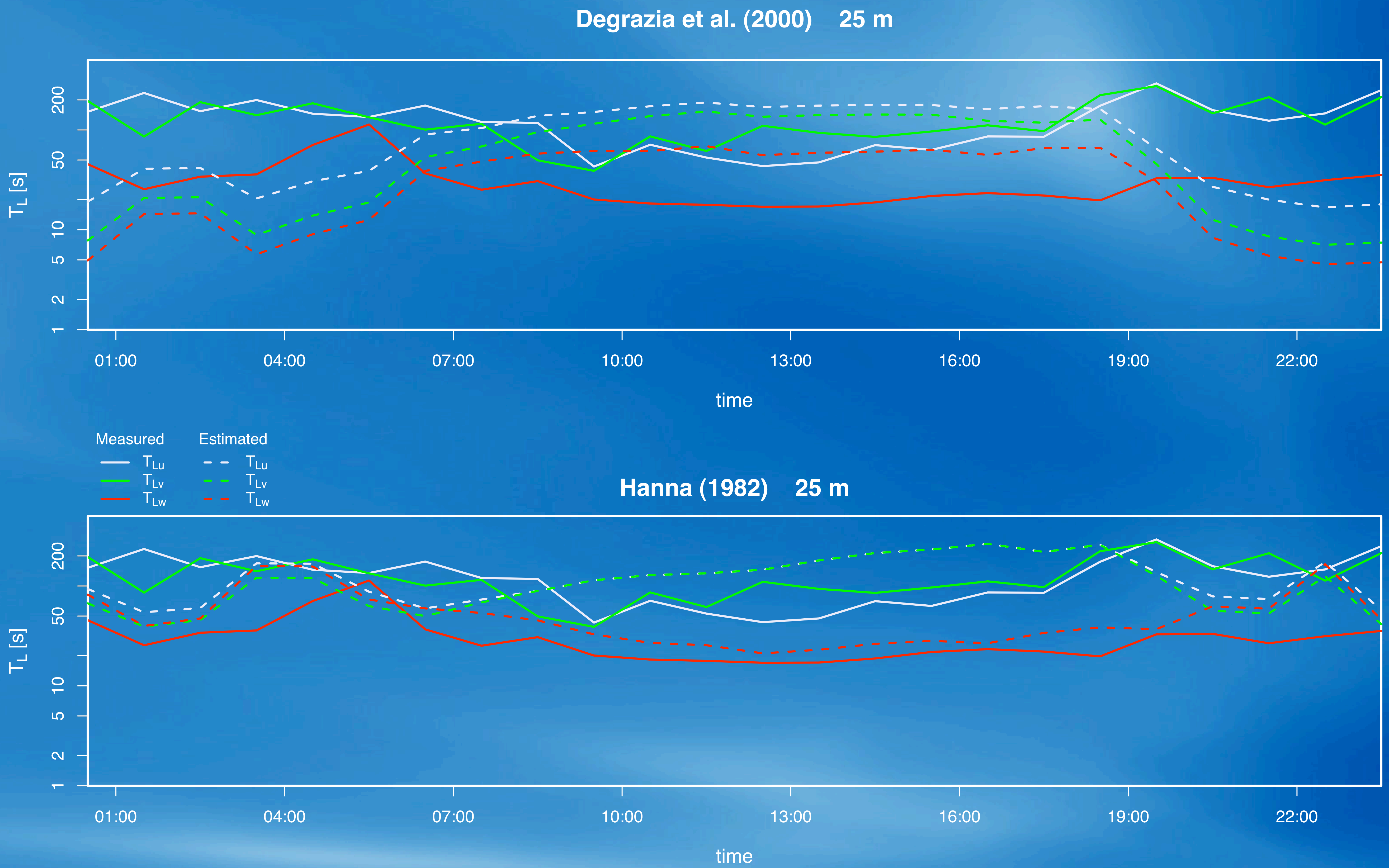


Lagrangian Time-Scale (9 m)





Lagrangian Time-Scale (25 m)



High-Order Statistics

In the *(S, K)* space an inferior limit for the Kurtosis exist (Kendall and Stuart, 1977):

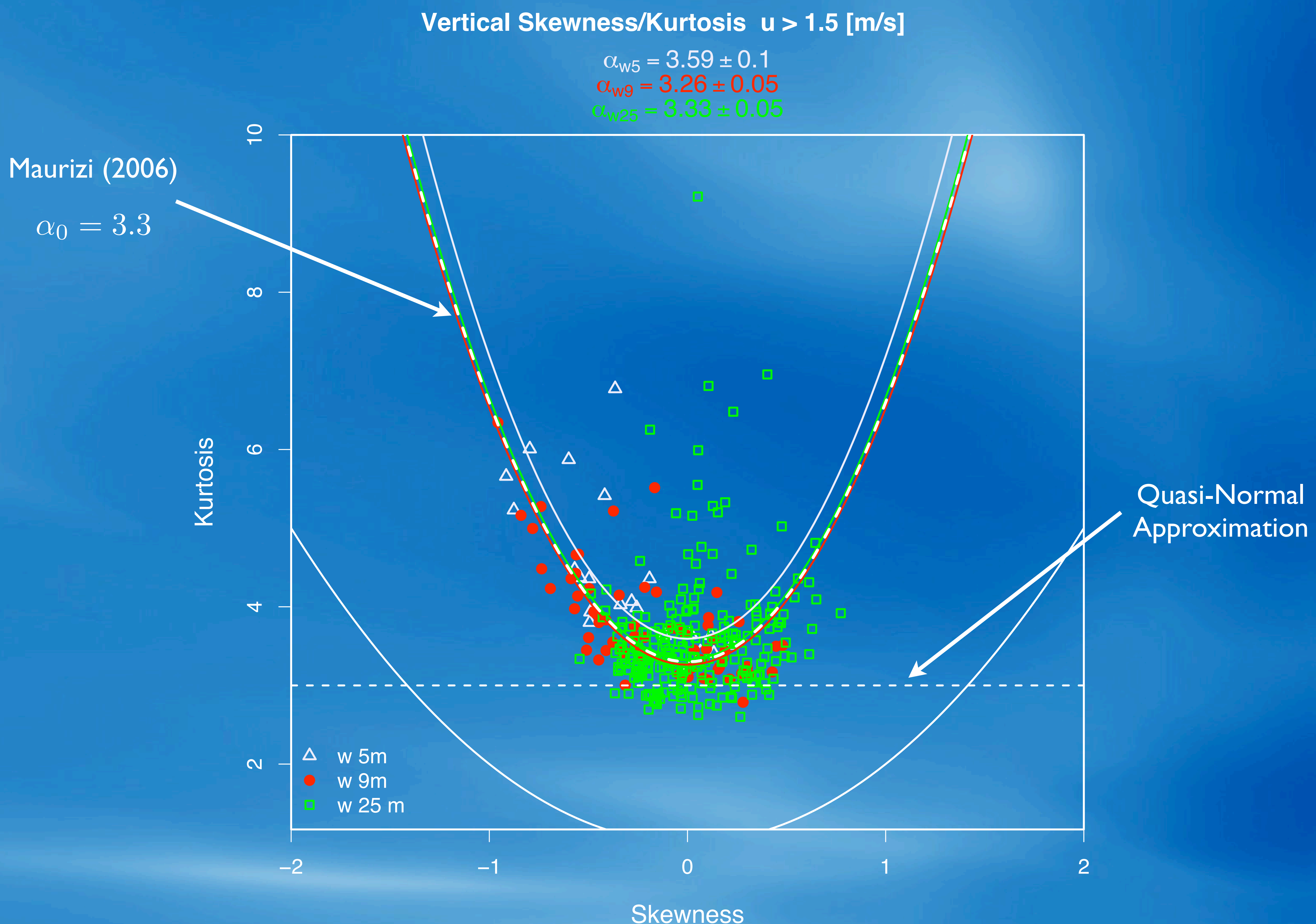
$$K \geq S^2 + 1$$

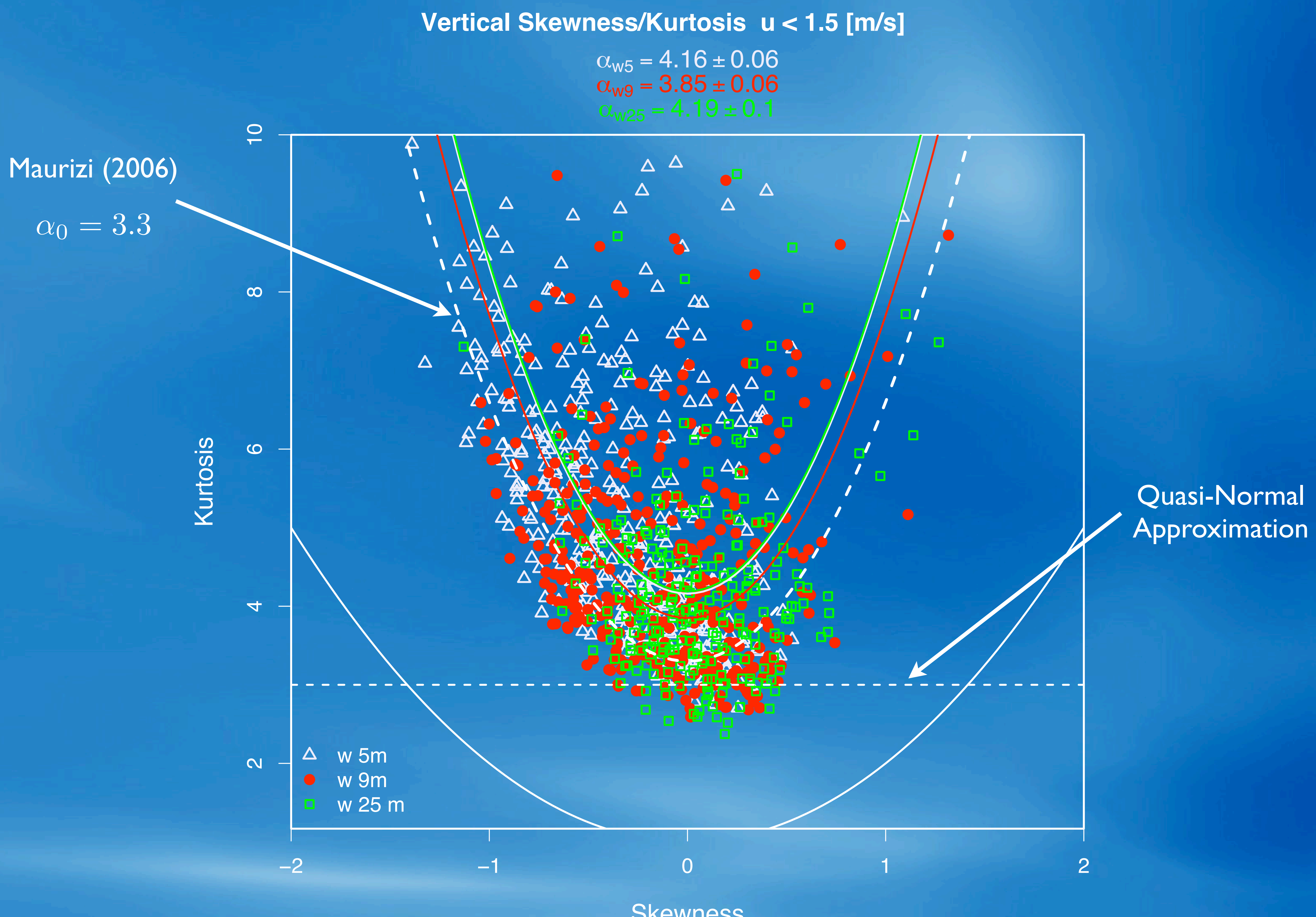
which limits the Quasi-Normal Approximation in the range of the Skewness values.
Tampieri et al. (2000) proposed the relation:

$$K = \alpha_0 \left(S^2 + 1\right)$$

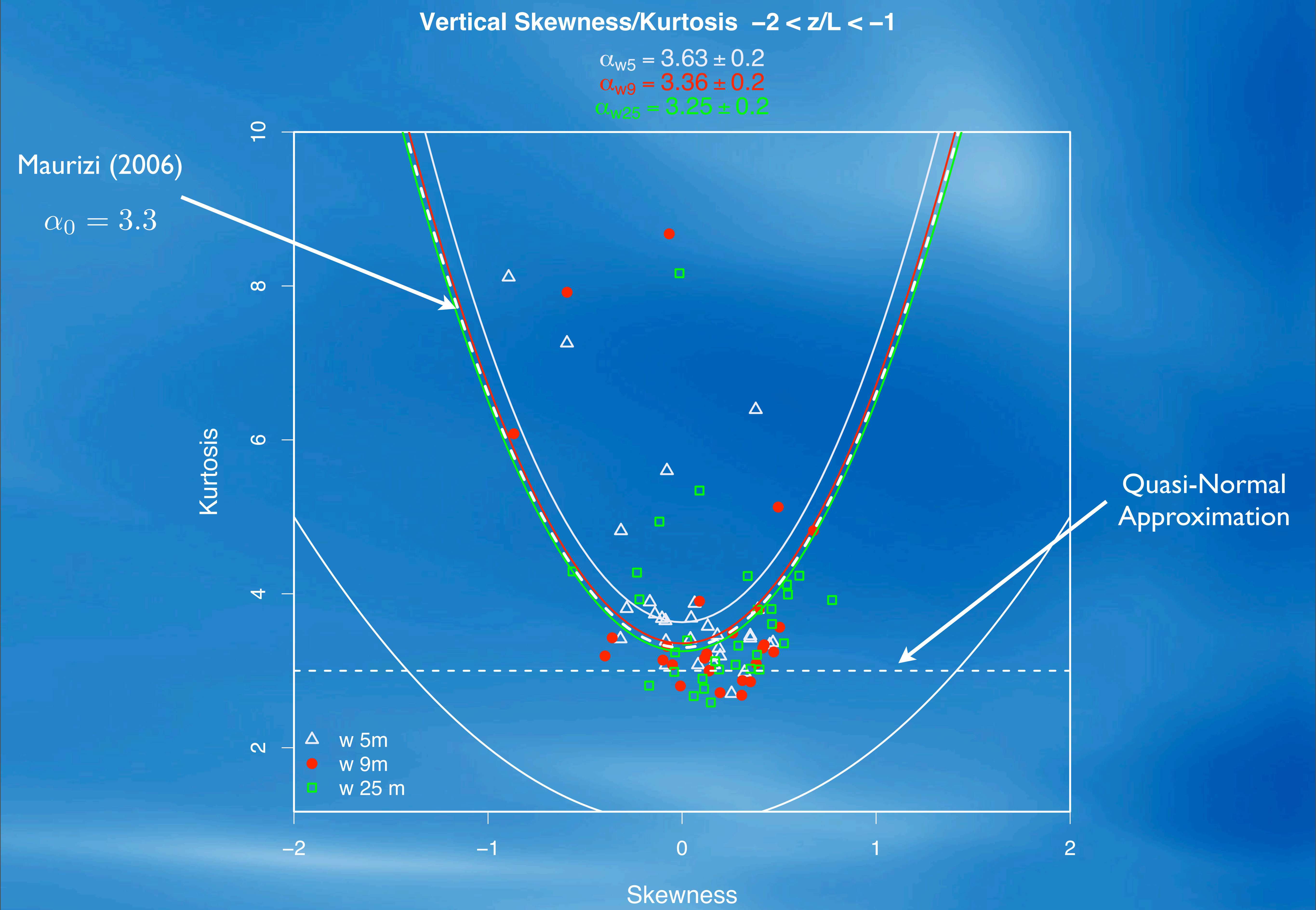
with $\alpha_0 = 3.3$ for a shear flow, Maurizi (2006) demonstrated that *K*-values above this curve correspond to damping terms for the turbulent kinetik energy and related these values to stable conditions, suggesting a dependence of α_0 on the stability:

$$\alpha_0 = \alpha_0 \left(\frac{z}{L}\right)$$

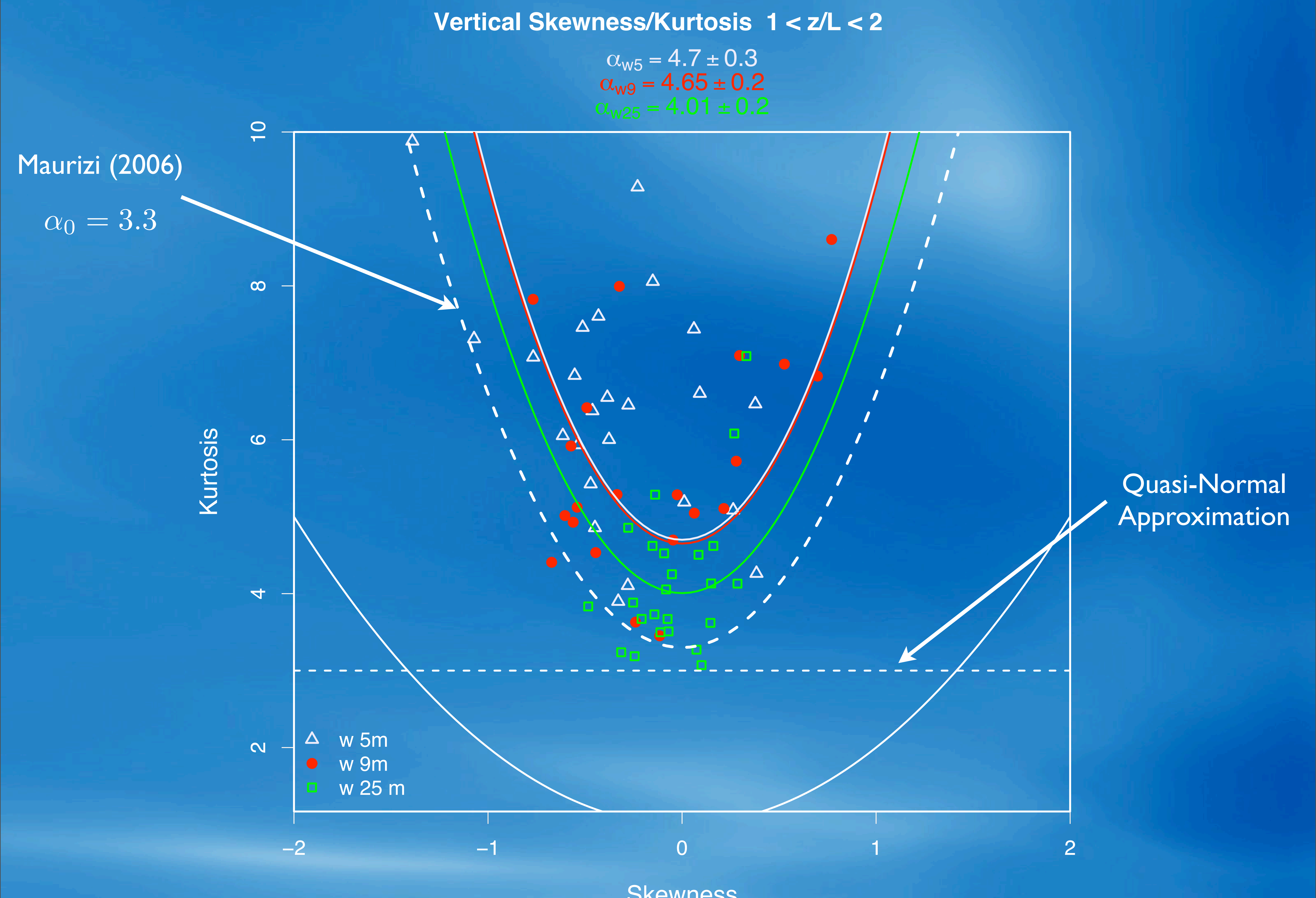

Vertical Skewness/Kurtosis u > 1.5 [m/s]
$\alpha_{w5} = 3.59 \pm 0.1$
$\alpha_{w9} = 3.26 \pm 0.05$
$\alpha_{w25} = 3.33 \pm 0.05$
Maurizi (2006)
$\alpha_0 = 3.3$
Quasi-Normal Approximation
Kurtosis
Skewness
10
8
6
4
2
−2
−1
0
1
2
w 5m
w 9m
w 25 m



Vertical Skewness/Kurtosis u < 1.5 [m/s]
$\alpha_{w5} = 4.16 \pm 0.06$
$\alpha_{w9} = 3.85 \pm 0.06$
$\alpha_{w25} = 4.19 \pm 0.1$
Maurizi (2006)
$\alpha_0 = 3.3$
Quasi-Normal Approximation
Kurtosis
Skewness
w 5m
w 9m
w 25 m
10
8
6
4
2
−2
−1
0
1
2

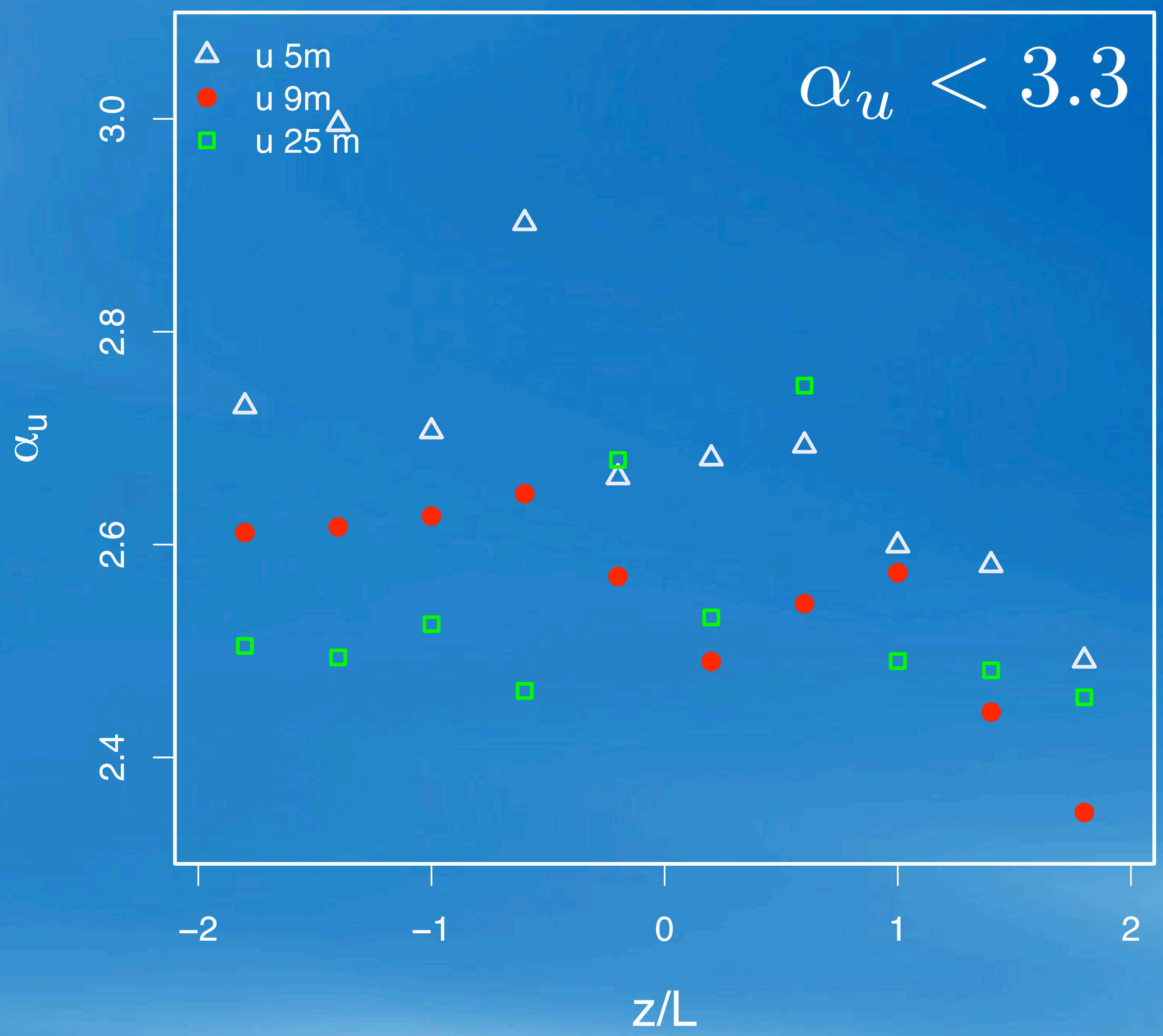


Vertical Skewness/Kurtosis –2 < z/L < –1
$\alpha_{w5} = 3.63 \pm 0.2$
$\alpha_{w9} = 3.36 \pm 0.2$
$\alpha_{w25} = 3.25 \pm 0.2$
Maurizi (2006)
$\alpha_0 = 3.3$
Quasi-Normal Approximation
Kurtosis
Skewness
10
8
6
4
2
–2
–1
0
1
2
w 5m
w 9m
w 25 m

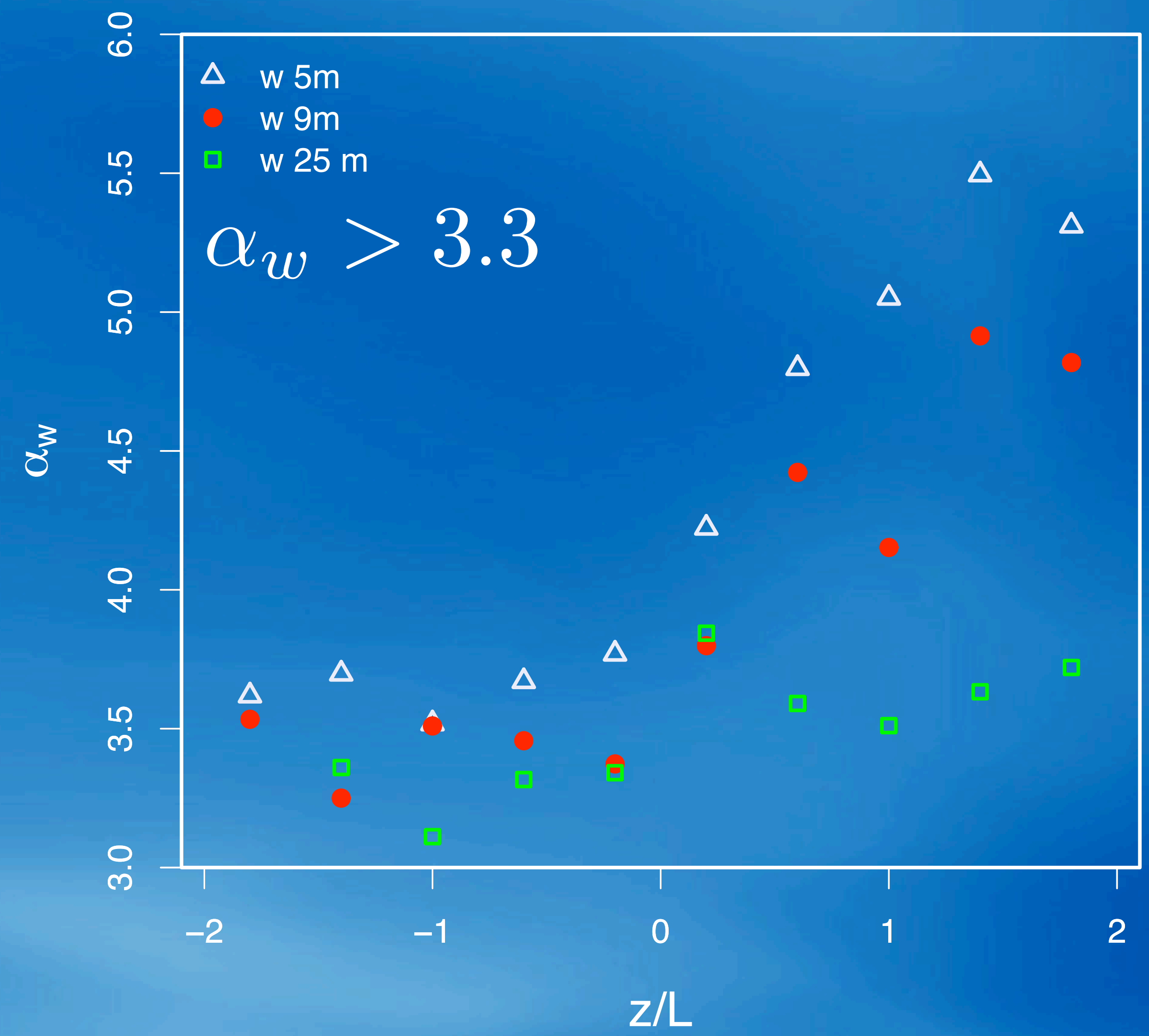

Vertical Skewness/Kurtosis 1 < z/L < 2
$\alpha_{w5} = 4.7 \pm 0.3$
$\alpha_{w9} = 4.65 \pm 0.2$
$\alpha_{w25} = 4.01 \pm 0.2$
Maurizi (2006)
$\alpha_0 = 3.3$
Quasi-Normal
Approximation
Kurtosis
Skewness
w 5m
w 9m
w 25 m
10
8
6
4
2
−2
−1
0
1
2

$$\alpha_0 = \alpha_0\left(\frac{z}{L}\right)$$

Stream–Wise Wind Velocity



Vertical Wind Velocity



Conclusions (i)

Parametrizations and Lagrangian Time-Scales

- The measured velocity standard deviations follows the Moraes et al. (2005) best fits, while the two considered parametrizations (Hanna, 1982 and Degrazia et al. (2002) underestimates the observations in stable conditions.

- Hanna (1982) T_L estimates perfectly fit the measured value,.

- Both parametrizations, as expected, are not able to take in to account the urban environment. In particular the Lagrangian Time-Scale behaviour during the day of the horizontal components is almost opposite to the parametrized ones.

(preliminary results)

Conclusions (ii)

High Order Moments

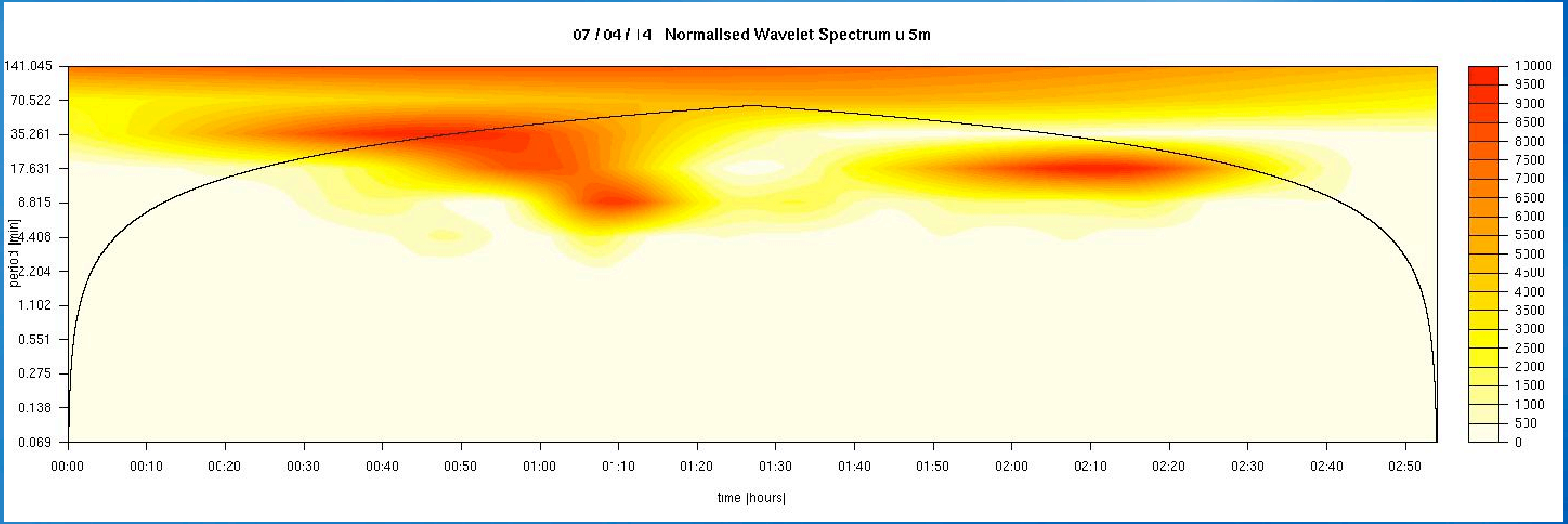
- For Low-Wind condition is it difficult to assume a parabolic dependence of the Kurtosis on the Skewness.

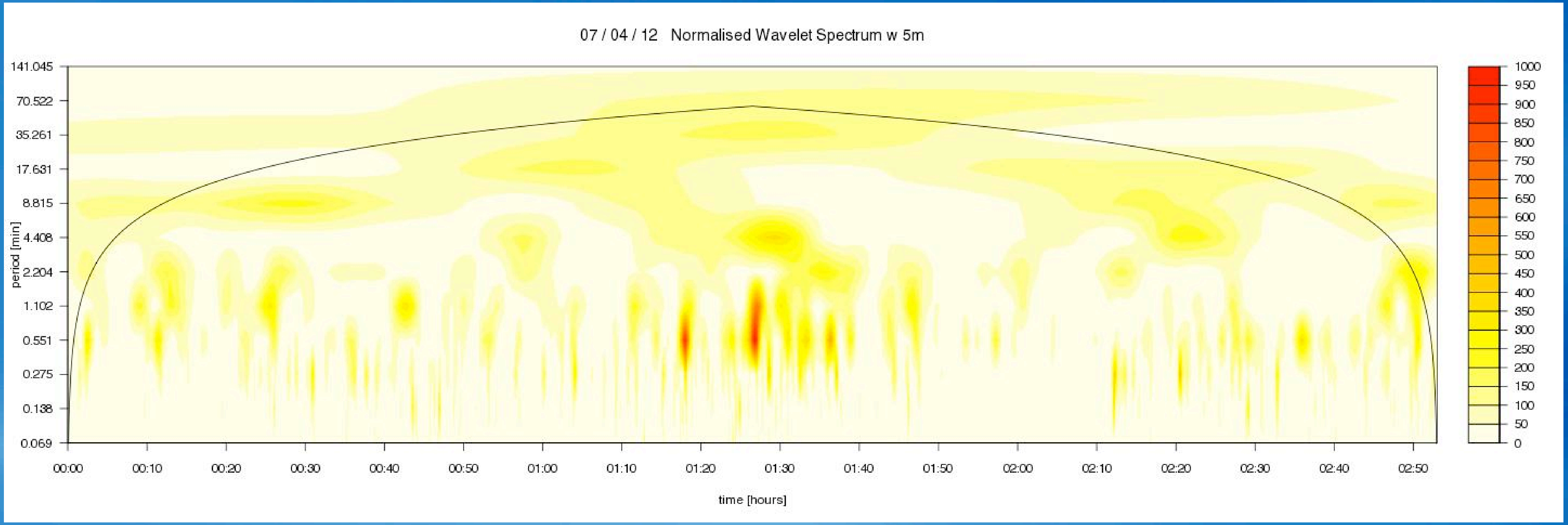
- The wind velocity vertical component shows a dynamic stability for low-wind and for stable conditions.

- The α_u e α_w coefficients shows an opposite dependence on z/L.

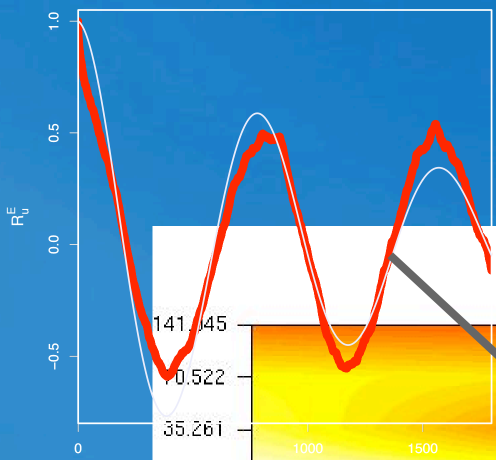
(preliminary results)

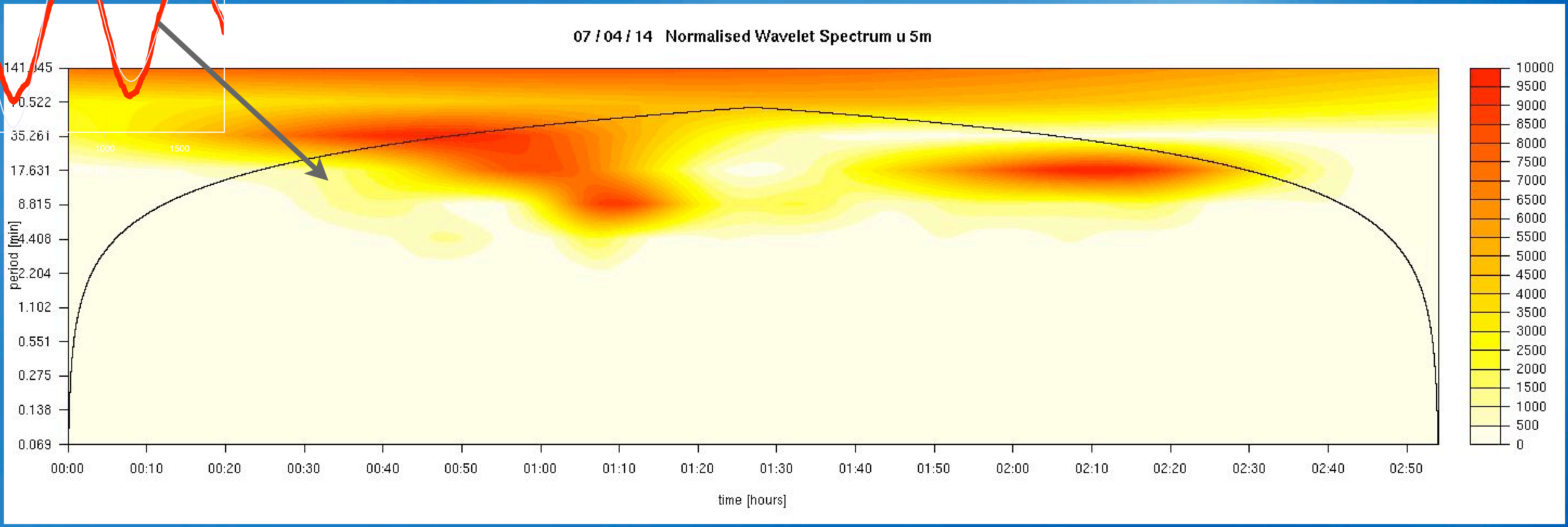
Future Works... Wavelets

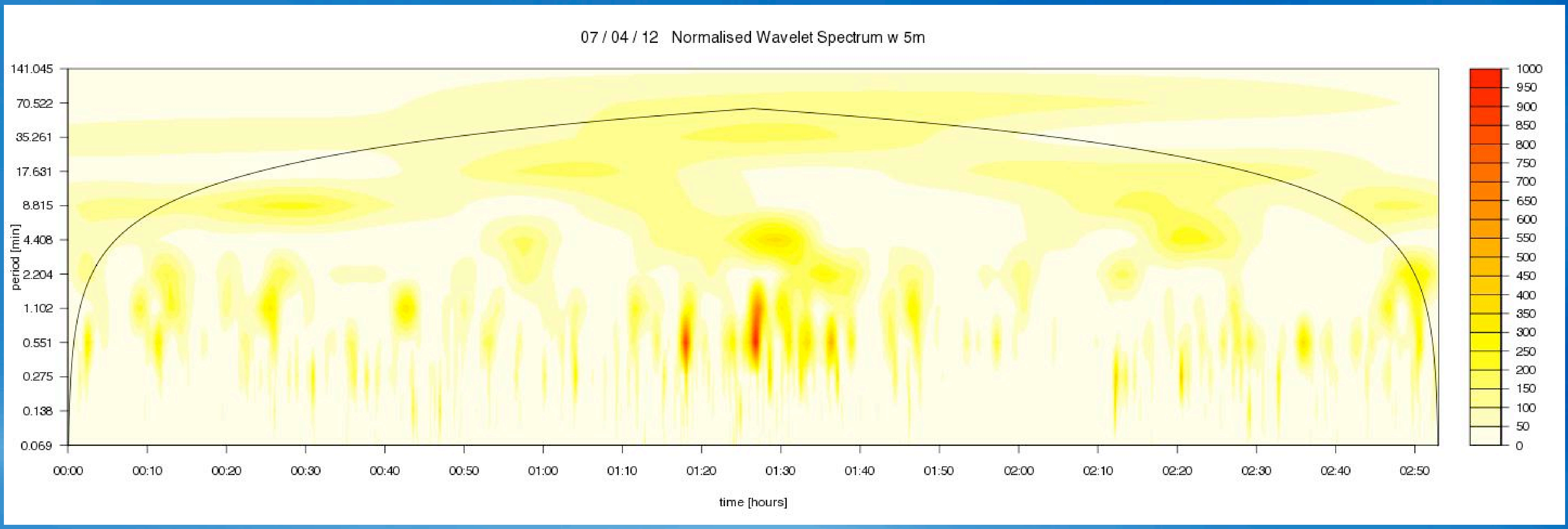




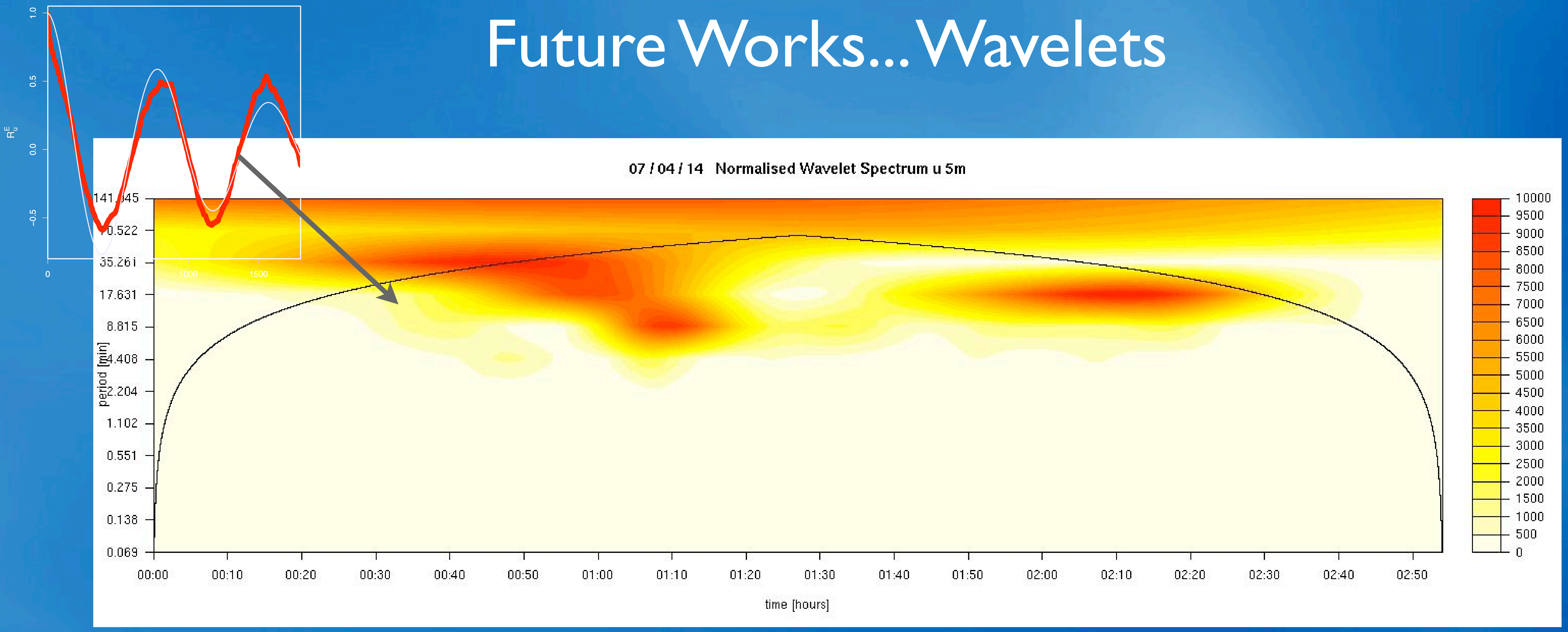
Future Works... Wavelets

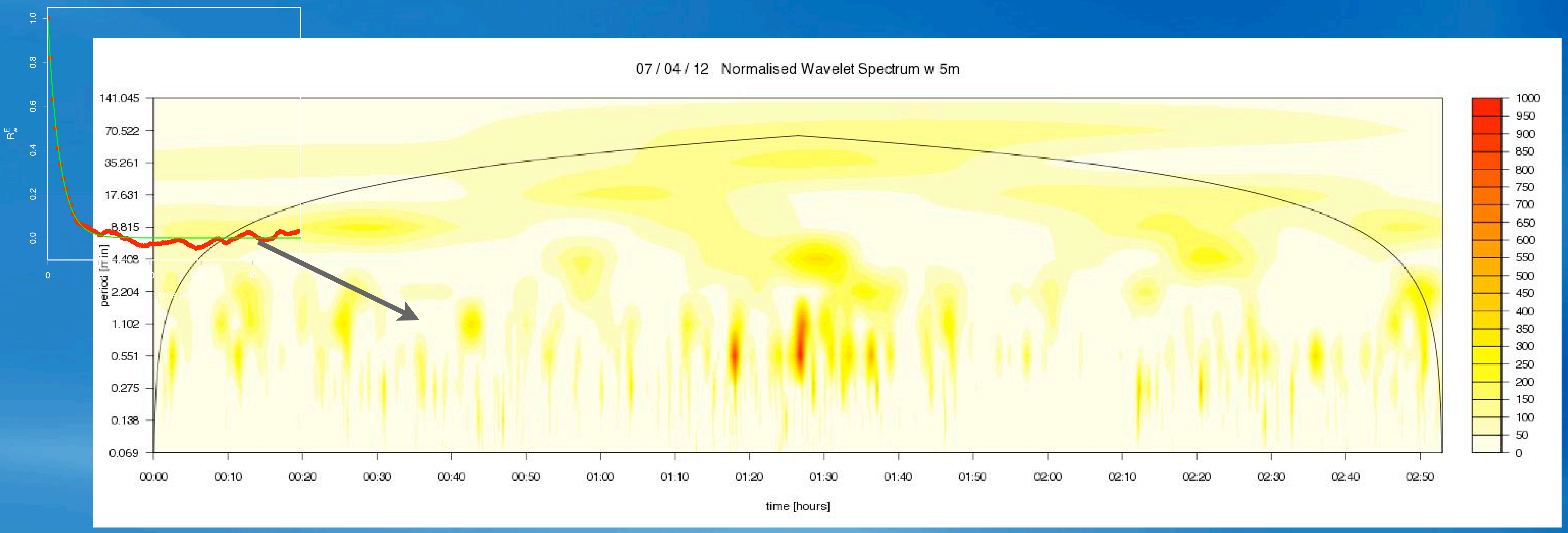






Future Works... Wavelets





Thank you!

l.mortarini@isac.cnr.it