Modelling Surface Wind for Ram-air Parachute Piloting Simulator

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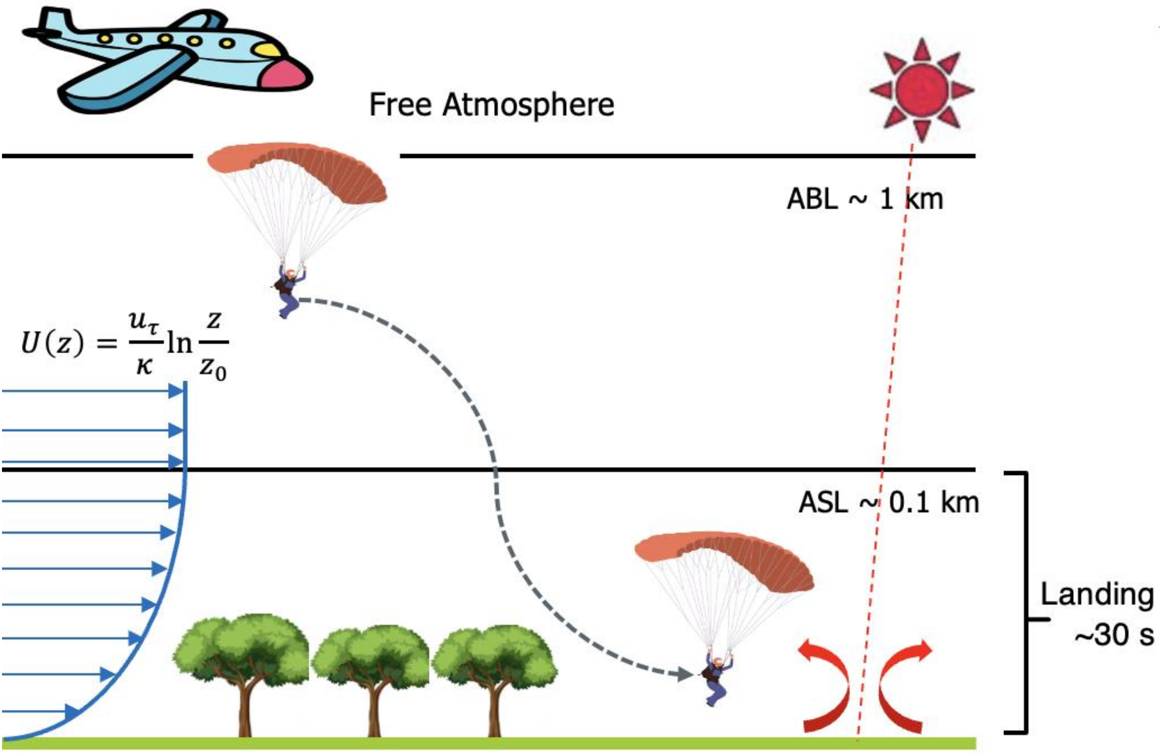
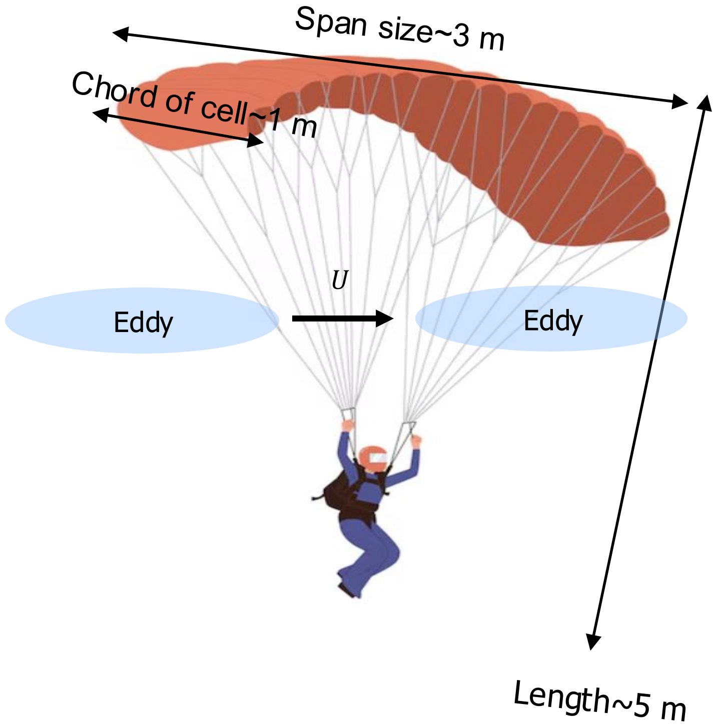
Flying Through the ASL





$$f = \frac{U}{\lambda} = \frac{10}{0.5} = 20\ [Hz]$$

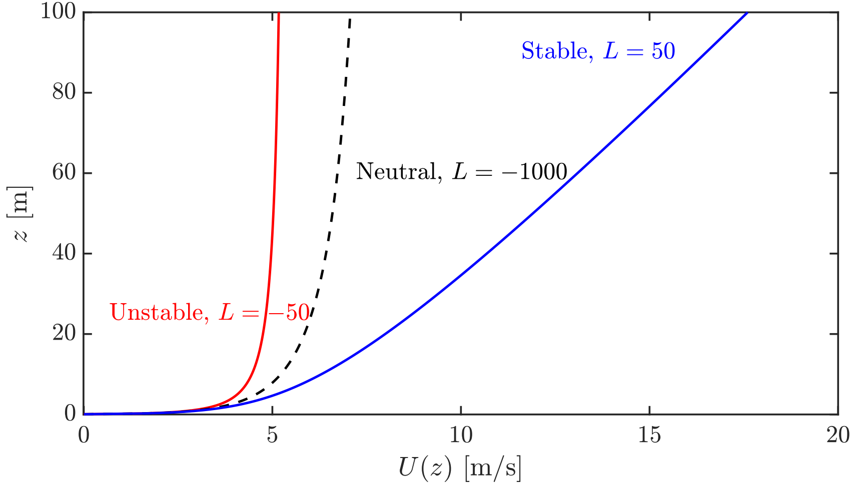
Modelling Mean Wind in the ASL

Mean velocity profile: $u = \boldsymbol{U} + u$

$$-\infty < \zeta = \frac{z}{L} < \infty, L = \frac{-u_\tau^3 \bar{\theta}}{kg\overline{H}}$$

$$\frac{\kappa z}{u_\tau} \frac{dU}{dz} = \phi_m(\zeta)$$

$$\frac{\kappa z}{\overline{H}} \frac{d\theta}{dz} = \phi_h\left(\frac{Z}{L}\right)$$



$\frac{z}{L} < 0$	$\frac{z}{L} > 0$	$\frac{z}{L} = 0$
$\phi_m\left(\frac{Z}{L}\right) = \left(1 - \beta_m \frac{Z}{L}\right)^{-1/4}$	$\phi_m\left(\frac{Z}{L}\right) = 1 + \beta_m \frac{Z}{L}$	$\phi_m\left(\frac{Z}{L}\right) = 1$
$\phi_h\left(\frac{Z}{L}\right) = \left(1 - \beta_h \frac{Z}{L}\right)^{-1/2}$	$\phi_h\left(\frac{Z}{L}\right) = 1 + \beta_h \frac{Z}{L}$	$\phi_h\left(\frac{Z}{L}\right) = 1$

Obukhov et al. (1946), Monin and Obukhov (1954)

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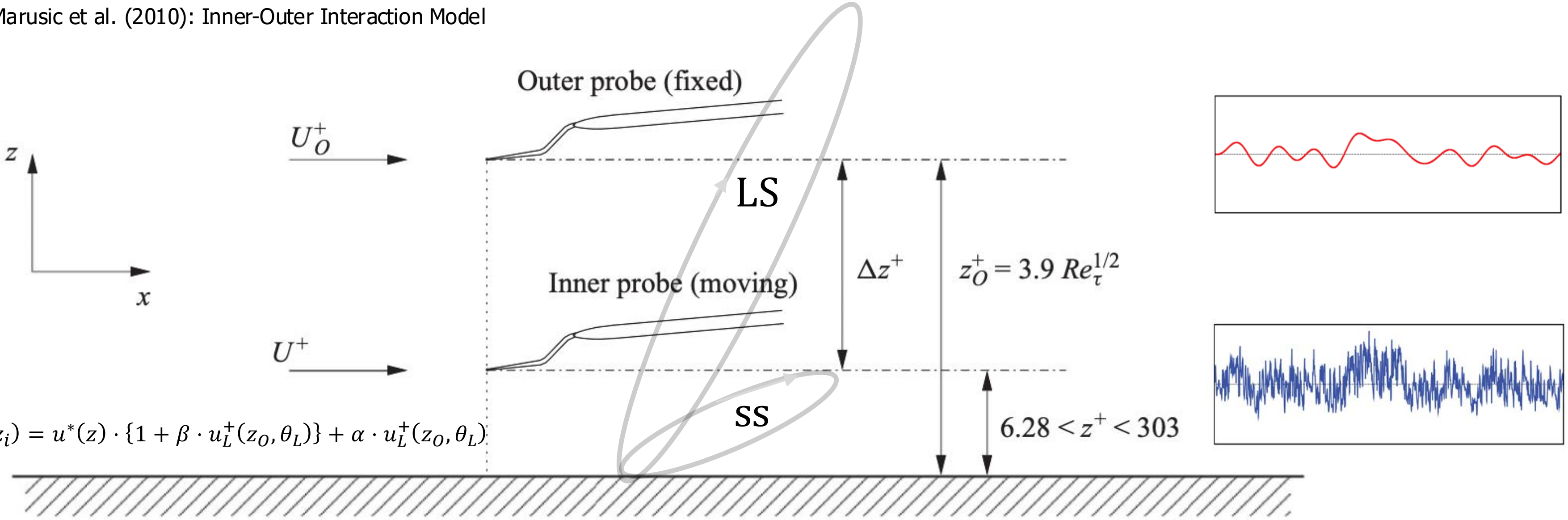
Modelling Turbulence

Higher order moments: $u = U + \boldsymbol{u}$

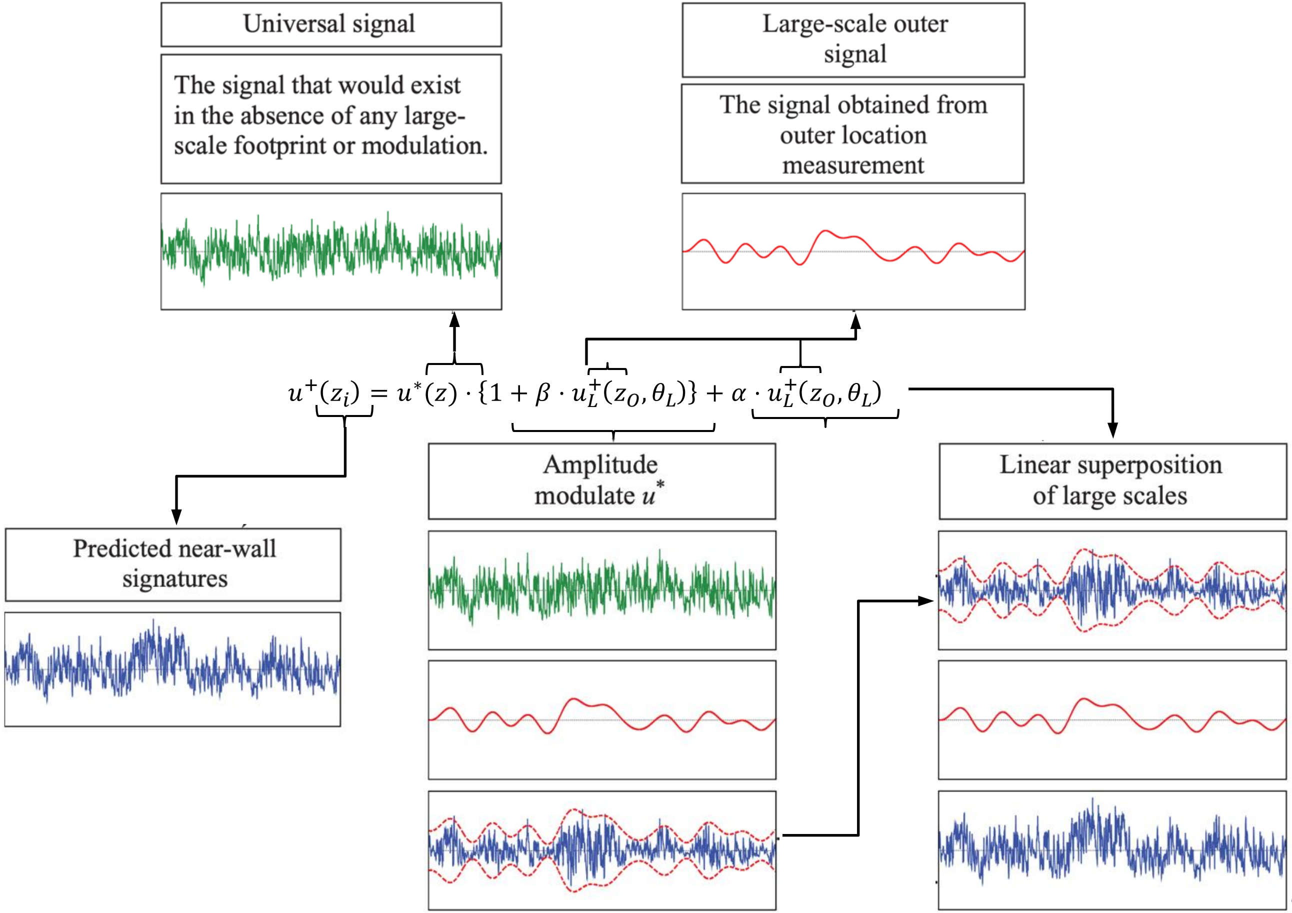
Marusic et al. (2010): Inner-Outer Interaction Model



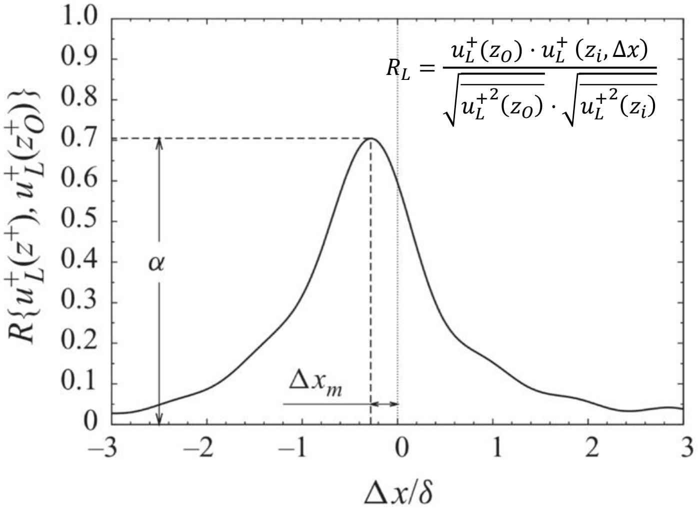
$$u^+(z_i) = u^*(z) \cdot \{1 + \beta \cdot u_L^+(z_O, \theta_L)\} + \alpha \cdot u_L^+(z_O, \theta_L)$$

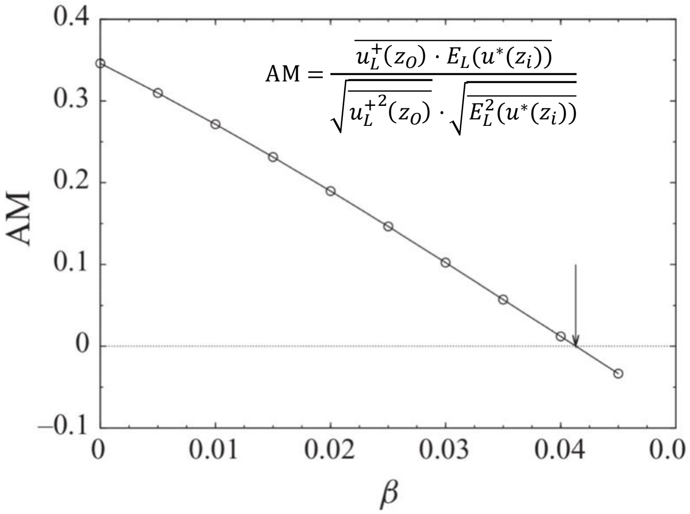
Inner-Outer Interaction Model

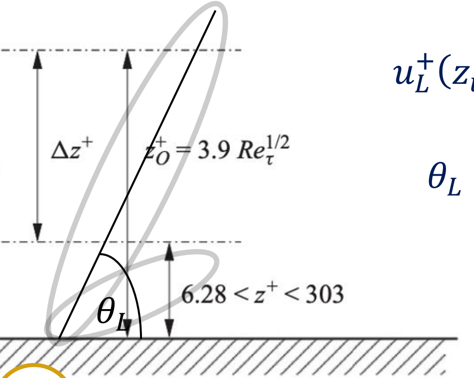
Mathis et al. (2011)



Parameters Determination







$$u_L^+(z_i) \approx \alpha \cdot u_L^+(z_O, \theta_L),$$

$$\theta_L = \arctan\frac{z_O - z_i}{\Delta x_m}$$

$$u_s^+(z_i) \approx u^+(z_i) - \alpha \cdot u_L^+(z_O, \Delta x_m)$$

$$u^*(z_i) \approx \frac{u_s^+(z_i)}{1 + \beta \cdot u_L^+(z_O, \Delta x_m)}$$

$$\mathrm{AM}\big(u^*(z_i)\big) = 0$$

$$u^+(z_i) = \underbrace{u^*(z) \cdot \{1 + \beta \cdot u_L^+(z_O, \theta_L)\}}_{u_s^+} + \underbrace{\alpha \cdot u_L^+(z_O, \theta_L)}_{u_L^+}$$

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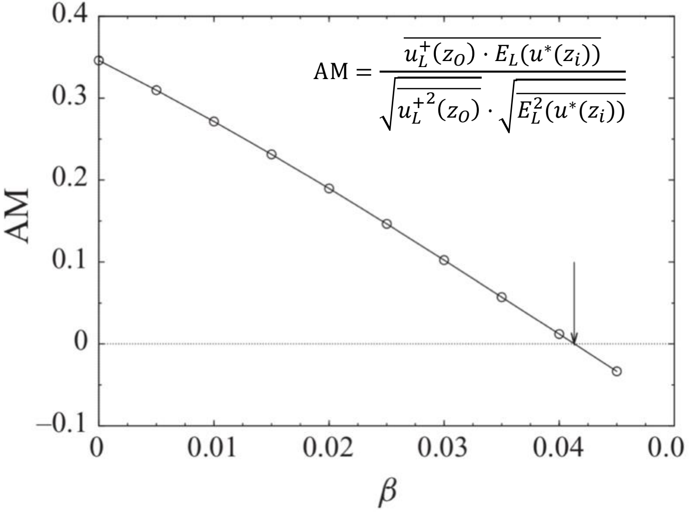
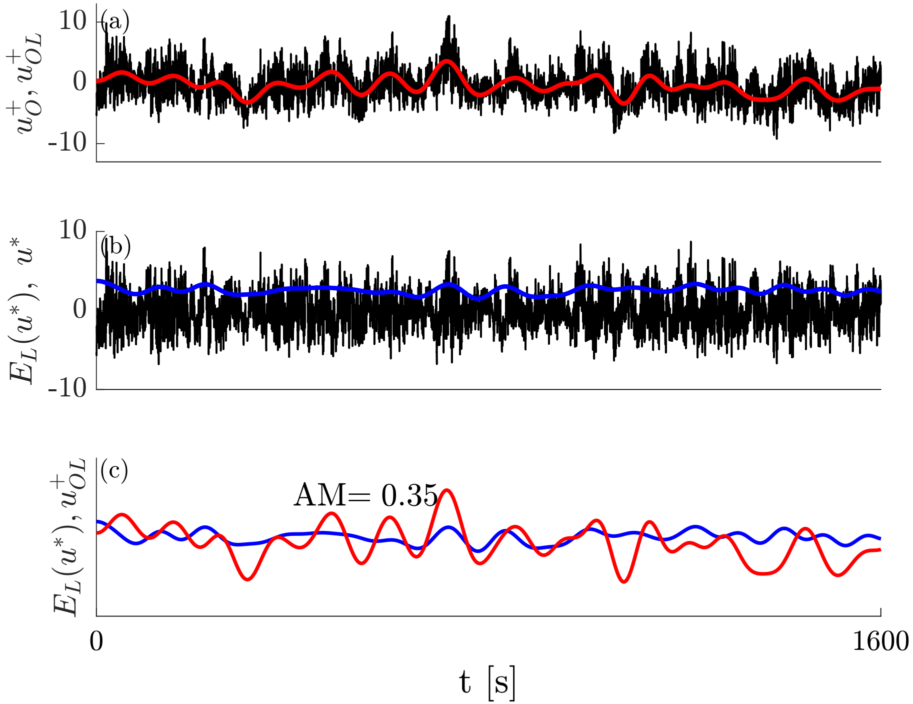
Parameters Determination





$$u_s^+(z_i) \approx u^+(z_i) - \alpha \cdot u_L^+(z_O, \Delta x_m)$$

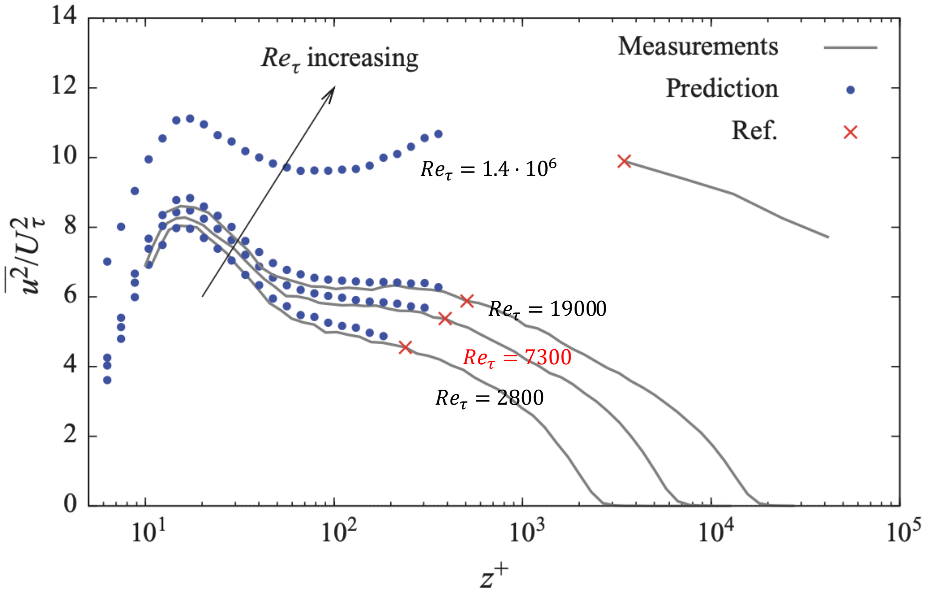
$$u^*(z_i) \approx \frac{u_s^+(z_i)}{1 + \beta \cdot u_L^+(z_O, \Delta x_m)}$$

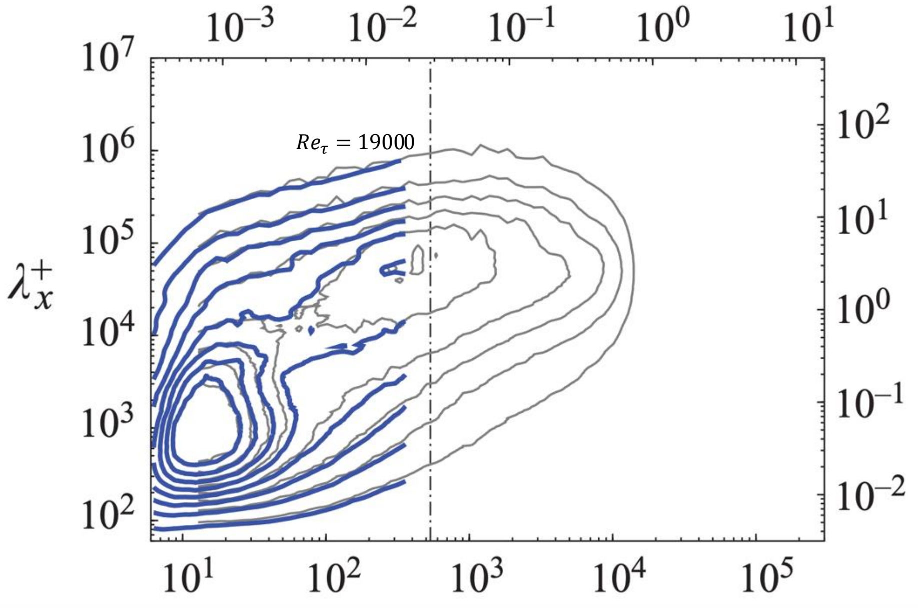
$$\mathrm{AM}\big(u^*(z_i)\big) = 0$$

$$u^+(z_i) = \underbrace{u^*(z) \cdot \{1 + \beta \cdot u_L^+(z_O, \theta_L)\}}_{u_s^+} + \underbrace{\alpha \cdot u_L^+(z_O, \theta_L)}_{u_L^+}$$

Mathis et al. (2011)

Inner Outer Interaction Model Predictions in Thermally Neutral Boundary Layers





$$Re_\tau = \frac{u_\tau \delta}{\nu}$$

Mathis et al. (2011)

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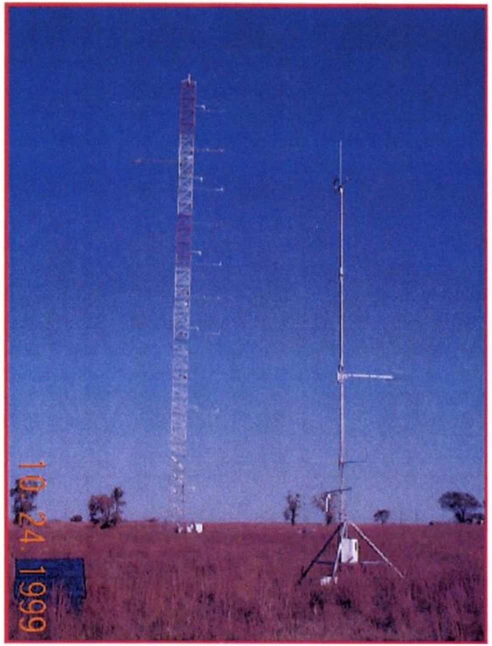
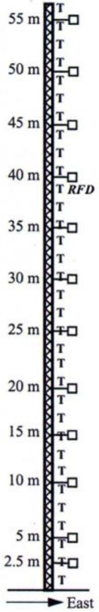
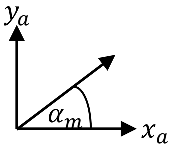
Inner-Outer Model in the ASL

CASES99





TOP VIEW

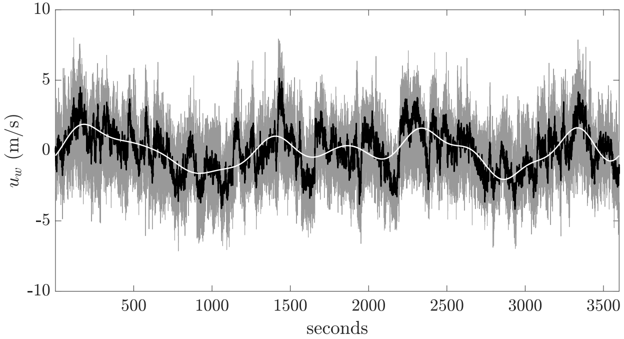


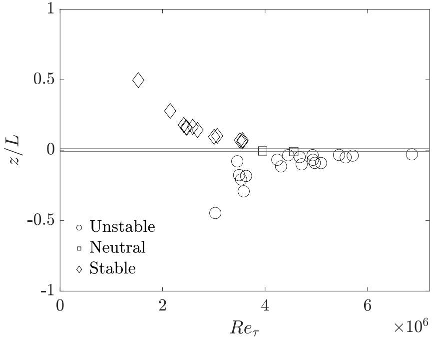
Measurements used:

- u, v, w, θ 20 Hz, $z = 0.5,5,10,20,30,40,50,55$ [m]

Processing stages:

- Hourly sections
- Dirction correction: $u_w = u_a \cos(\alpha_m) + v_a \sin(\alpha_m)$
- De-trending, $\delta = 150$ [m], $\lambda_{x,\mathrm{detrending}} = 20\delta$
- $u_\tau = \overline{u_w w}$, $\frac{z}{L} = -\frac{zkg\overline{w\theta}}{u_\tau^3 \overline{\theta}}$, both calculated at $z = 5$ [m]
- Stationarity





Poulos et al. (2002), Drobinski et al. (2004)

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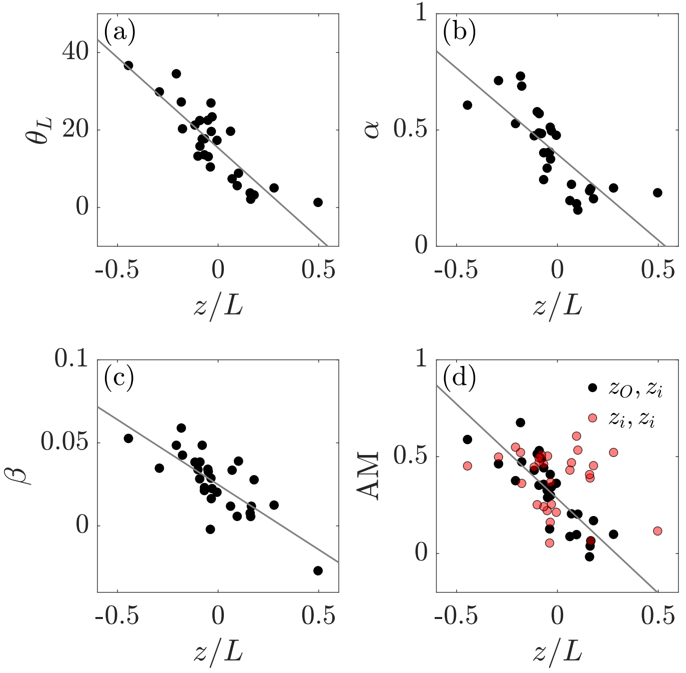
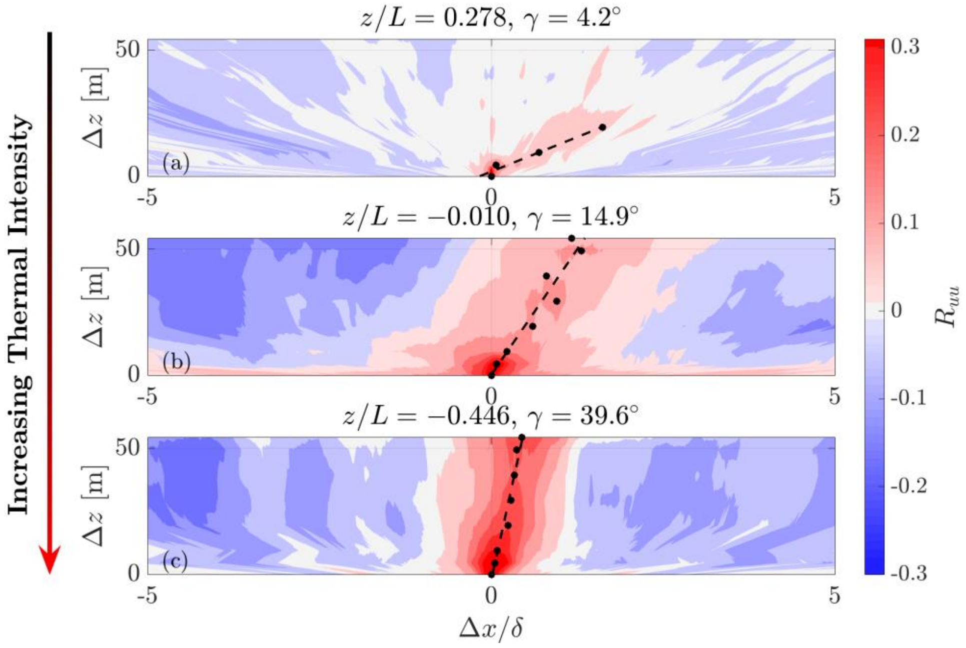
Stability Dependance of the Large-Scale Model Parameters

$z_O = 10$ [m], $z_i = 0.5$ [m]





$$R_{uu} = \frac{u^+(z_O)\cdot u^+(z_i,\Delta x)}{\sqrt{\overline{u^{+2}(z_O)}}\cdot\sqrt{\overline{u^{+2}(z_i)}}}$$

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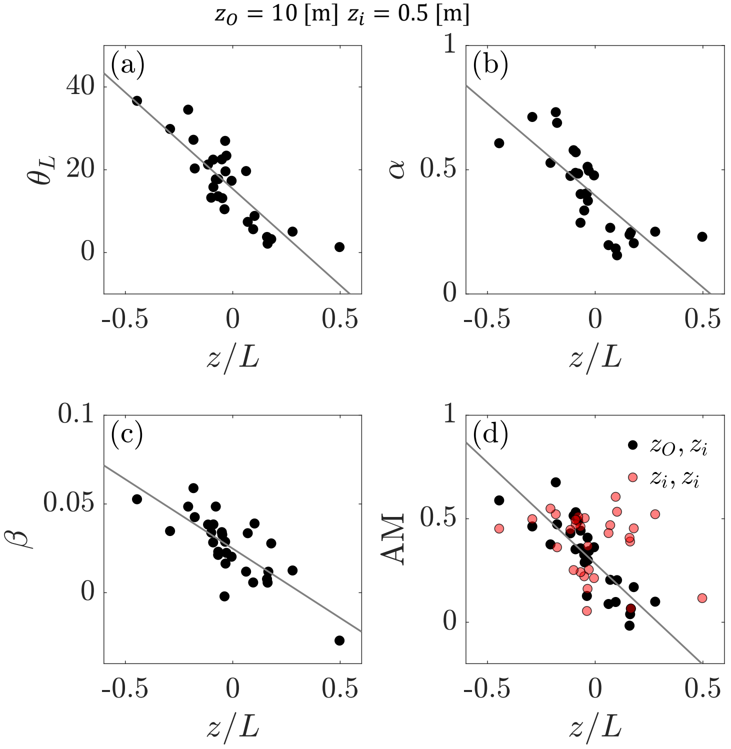
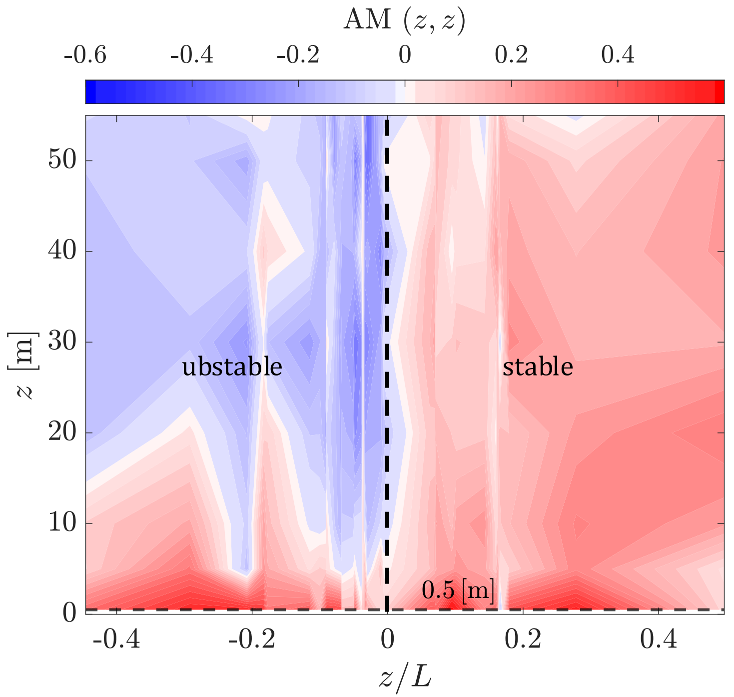
Stability Dependance of the Small-Scale Model Parameters





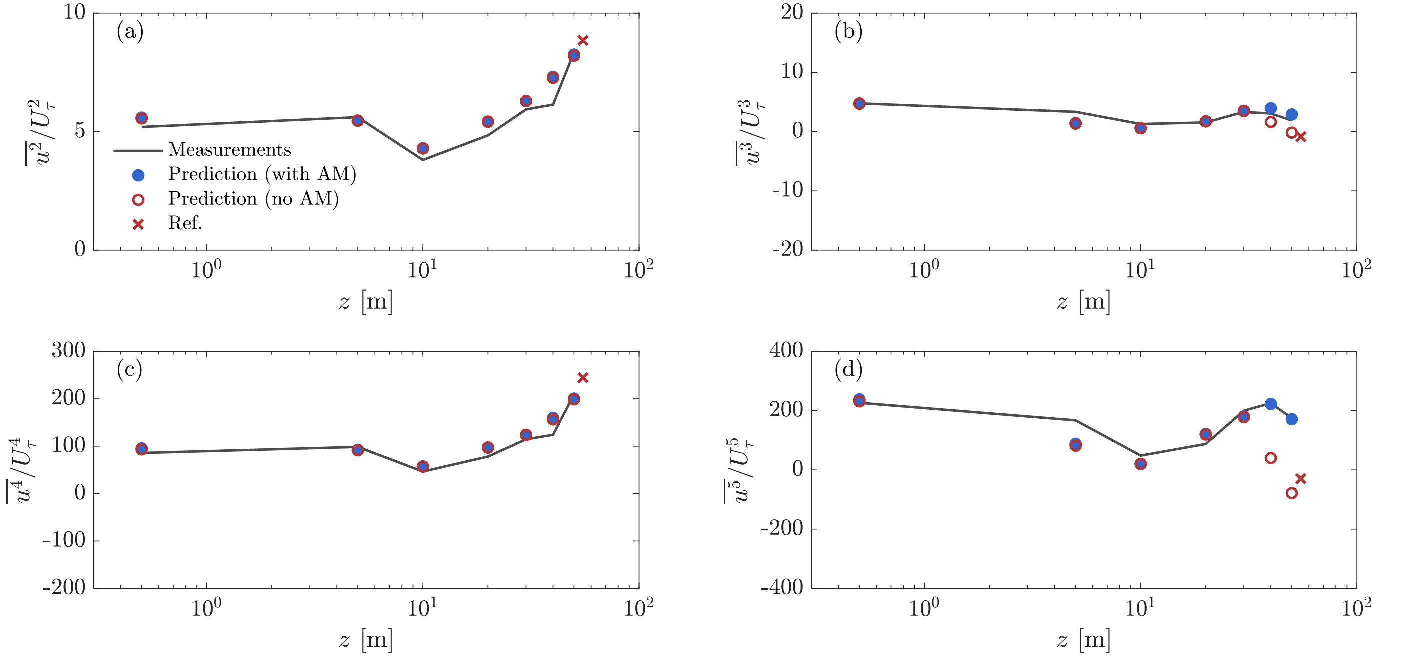
$$\mathrm{AM} = \frac{\overline{u_L^+(z) \cdot E_L(u_s(z))}}{\sqrt{\overline{u_L^{+2}(z)}} \cdot \sqrt{\overline{E_L^2(u_s(z))}}}$$

Prediction using the Inner-Outer Model- statistics

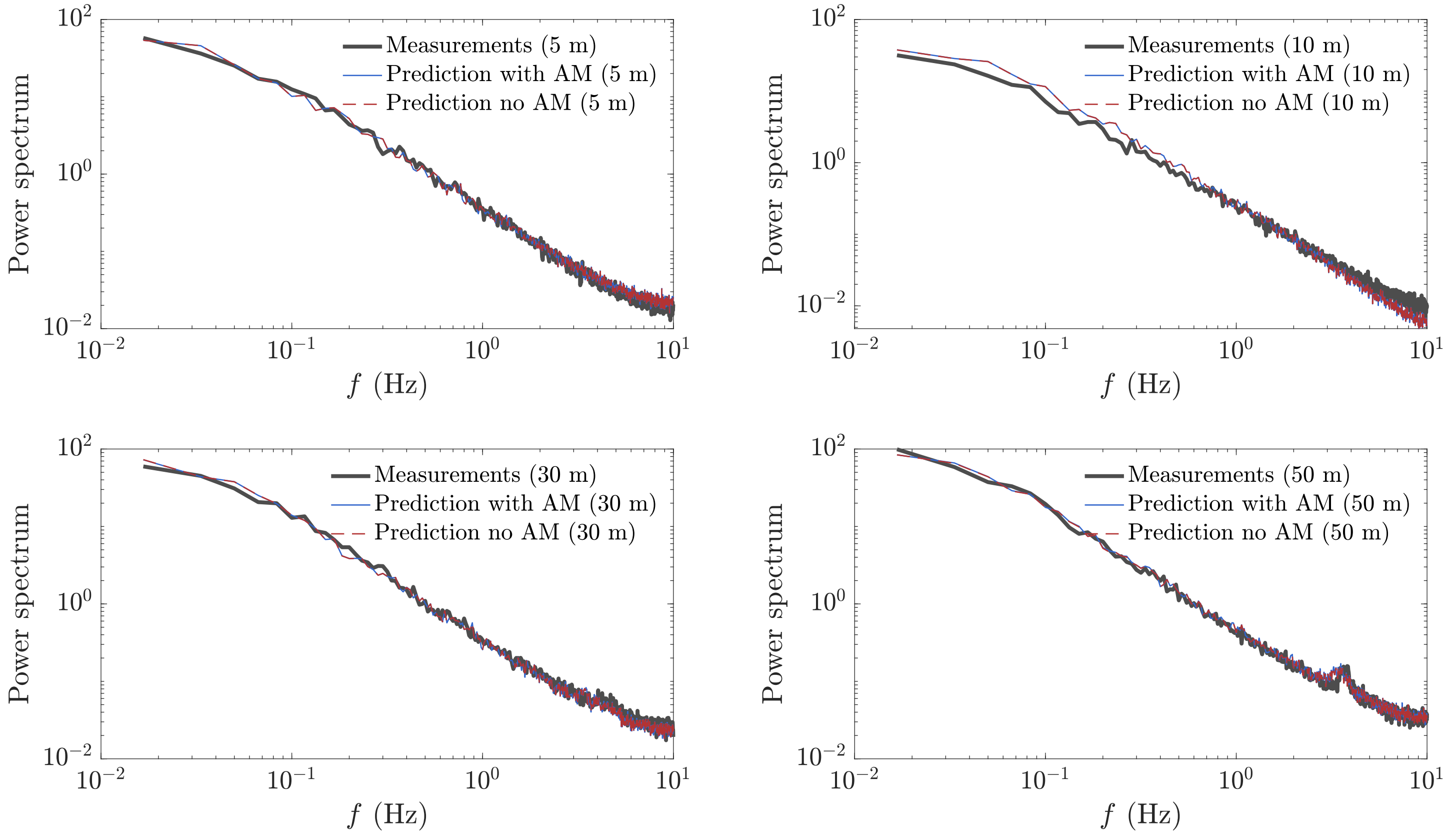
	Model parameters determination	Model validation
z/L	$0.159 \rightarrow \alpha, \beta, \theta, u^*$	0.162
Time and date (CST)	24-Oct-1999 22:00:00	27-Oct-1999 21:00:00

$$\text{with AM: } u^+(z_i) = u^*(z) \cdot \{1 + \beta \cdot u_L^+(z_O, \theta_L)\} + \alpha \cdot u_L^+(z_O, \theta_L)$$

$$\text{no AM: } u^+(z_i) = u^*(z) \cdot \{1 + 0 \cdot u_L^+(z_O, \theta_L)\} + \alpha \cdot u_L^+(z_O, \theta_L)$$

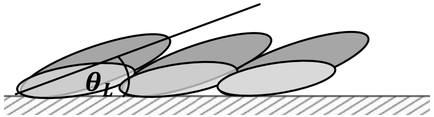


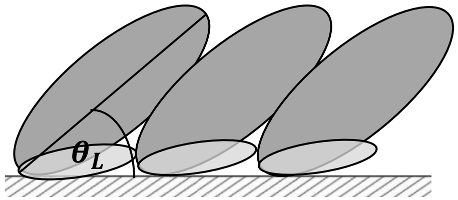
Prediction using the Inner-Outer Model- spectra



Conclusion

- Thermal stability affects the inner-outer model parameters. Stability suppresses mixing, limiting large-scale correlation.
- Spectra and moments up to fifth order are predicted well if the calibration signal have approximately the same stability condition.
- Amplitude modulation effect is expressed in the odd moments of turbulence.





Thank you!