4A.1: Amplitude modulation of streamwise velocity fluctuations in the roughness sublayer: evidence from large-eddy simulations

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Evidence of very long meandering features in the logarithmic region of turbulent boundary layers

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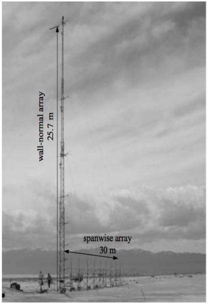

FIGURE 12. View of the measurement array installed at the SLTEST site.

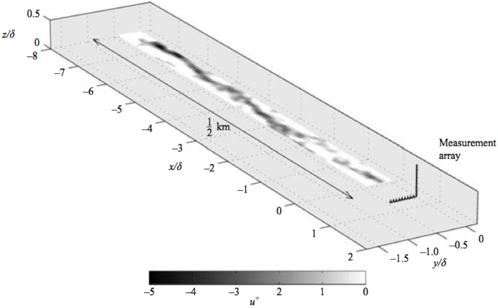

FIGURE 14. Example of signal across the spanwise array of sonic anemometers at SLTEST, $z/\delta = 0.037$, $Re_\tau = 660\,000$. The x-axis is reconstructed using Taylor's hypothesis and a convection velocity based on the local mean, $\overline{U} = 5.46\,\mathrm{m\,s^{-1}}$. Shading shows only negative u fluctuations (see grey scale).

Boundary-Layer Meteorol (2015) 155:397–416
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ARTICLE

Large-Eddy Simulation of Very-Large-Scale Motions in the Neutrally Stratified Atmospheric Boundary Layer

Jiannong Fang · Fernando Porté-Agel

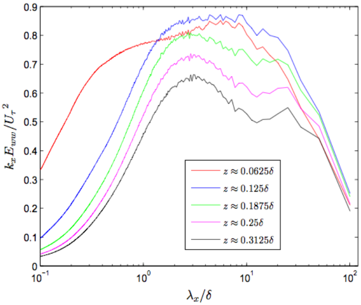
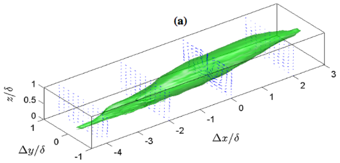


Fig. 4 Pre-multiplied power spectra as functions of the streamwise wavelength for the streamwise velocity component at various heights



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Conditionally averaged large-scale motions in the neutral atmospheric boundary-layer: insights for aeolian processes

Chinthaka Jacob · William Anderson

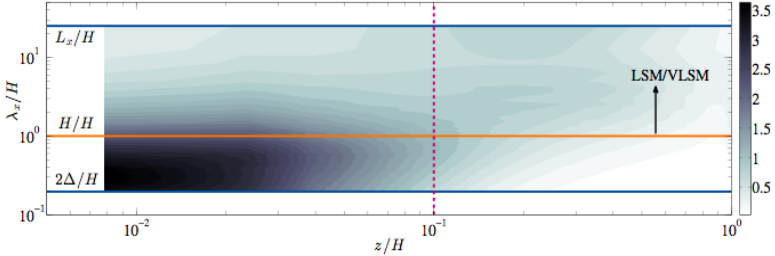


Fig. 4 Pre-multiplied energy spectrum of fluctuating streamwise velocity for case LES1, where colorbar shows $k_x E_{\tilde{u}'\tilde{u}'}/u_*^2$. Figure includes annotations of key geometric scales associated with problem: horizontal blue lines denote domain extent (L_x) and grid resolution (Δ), while horizontal line denotes domain depth, H. Vertical orange line denotes $z/H = 0.1$, or the elevation above which large-scale content associated with large- and very-large-scale motions should be present (Fang and Porté-Agel, 2015).

Science AAAS

Predictive Model for Wall-Bounded Turbulent Flow
I. Marusic *et al.*
Science **329**, 193 (2010);
DOI: 10.1126/science.1188765

Predictive Model for Wall-Bounded Turbulent Flow

I. Marusic,* R. Mathis, N. Hutchins

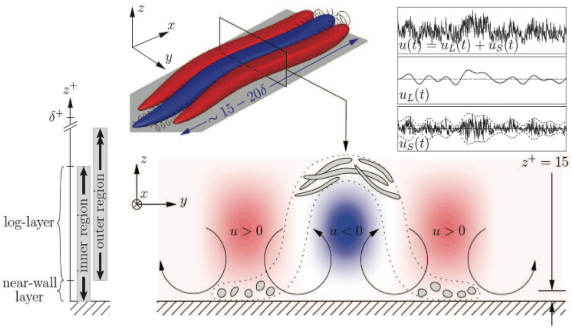
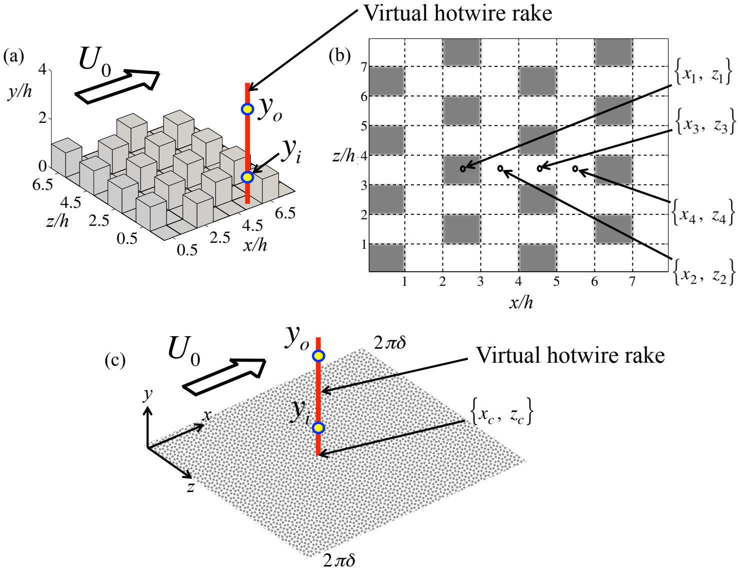


Fig. 1. Schematic of organized coherent flow motion known as a superstructure and its interaction across the turbulent boundary layer. These very-large-scale motions extend from the log region down toward the wall, both superimposing their signature and modulating the near-wall region. The sample u time series highlight the modulation effect of the large scales on the small scale at $z^+ = 15$; the near-wall location corresponds to the peak turbulence intensity. The features shown in gray indicate elongated filamentary vortex structures and their conjectured alignment with the superstructure.

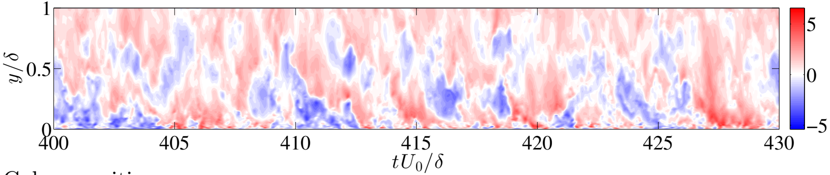
Inner-Outer Interactions: Amplitude Modulation of Roughness Sublayer



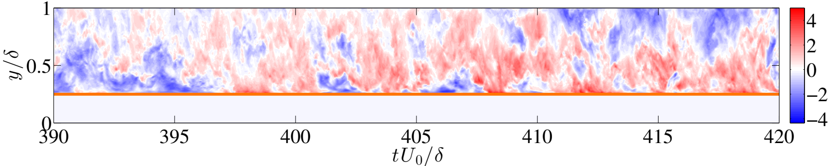
Record time-series of velocity across depth of domain (red line)

Time-height contours of $\tilde{u}'(x_l, y, z_l, t) = \tilde{u}(x_l, y, z_l, t) - \langle \tilde{u}(x_l, y, z_l, t) \rangle_T$

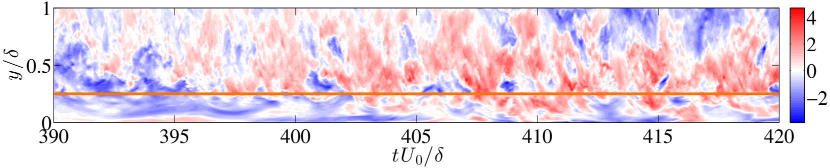
Homogeneous topography:



Cubes, position x_1:



Cubes, position x_4:



Inertial layer momentum excess(deficit) precedes roughness sublayer excitation(relaxation)

Inner-Outer Interactions: Amplitude Modulation of the Roughness Sublayer

Marusic et al., 2010: *Science*: $u_p(y_i) = \underbrace{u_*(1+\beta u_L(y_O))}_{\text{Amplitude Modulation}} + \underbrace{\alpha u_L(y_O)}_{\text{Superposition}}$

$u_p(y_i)$: Predicted velocity at inner elevation, y_i

u_*: Universal velocity, free of modulation or superposition

β: Amplitude modulation parameter; α: Superposition parameter

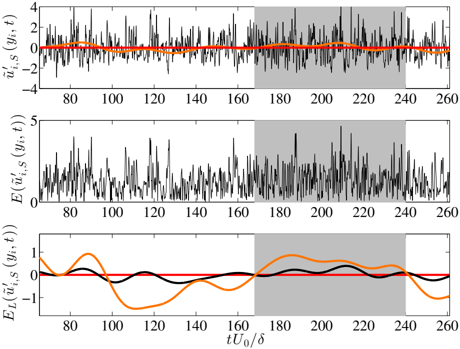
$\alpha u_L(y_O)$: Large-scale (low-pass filtered, $u_L(y_O,t) = G_\delta \star u(y_O,t)$) outer velocity

Marusic et al.: "***The simple algebraic form of Eq. 1*** [sic] ***is an ideal basis for a near-wall model for high-Re large-eddy simulations.***"

Mathis et al., 2009: *J. Fluid Mech.*: amplitude modulation decoupling procedure:

1. $\tilde{u}'(y,t) = \tilde{u}(y,t) - \langle \tilde{u}(y,t) \rangle_T$
2. $\tilde{u}'_L(y,t) = G_\delta \star \tilde{u}'(y,t)$, where $\hat{G}_\delta = H_s(k_c - |k|)$ and $k_c = 2\pi/\delta$ (one large-eddy turnover)
3. $\tilde{u}'_S(y,t) = \tilde{u}'(y,t) - \tilde{u}'_L(y,t)$
4. Hilbert transform complex analytic, $Z(t) = \tilde{u}'_S(y,t) + i\mathcal{H}(t) = A(t)e^{i\phi(t)}$
5. Low-pass filtered envelope of small scales, $E_L(\tilde{u}'_S(y,t)) = G_\delta \star A(t)$

Time series: homogeneous roughness



Top figure: $\tilde{u}'_S(y_i,t)$ (black); $\tilde{u}'_L(y_i,t)$ (orange); $y_i/\delta = 0.004$

Middle figure: $E(\tilde{u}'_S(y_i,t))$ (black); $y_i/\delta = 0.004$

Bottom figure: $E_L(\tilde{u}'_S(y_i,t))$ (black); $\tilde{u}'_L(y_O, t - \delta\tau(y_O; y_i))$ (orange); $y_O/\delta = 0.1$

$$\frac{y_O}{y_i} = 25$$

$\delta\tau(y; y_{\mathrm{Ref.}}) \equiv$ advective correction [Anderson et al., 2015: *J. Turb.*]

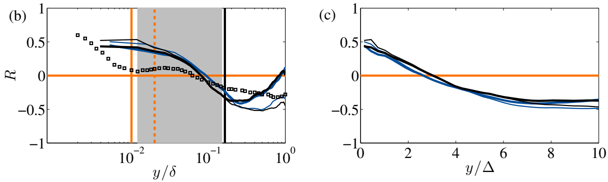
Correlation: homogeneous roughness

Single-point: $R(y;y) = \dfrac{\langle \tilde{u}'_L(y,t) E_L(\tilde{u}'_S(y,t)) \rangle_T}{\langle \tilde{u}'^2_L(y,t) \rangle_T^{1/2} \langle E_L^2(\tilde{u}'_S(y,t)) \rangle_T^{1/2}}$

Large-scale signal and envelope of small scales at same elevation

Two-point: $R(y;y_{\mathrm{Ref.}}) = \dfrac{\langle \tilde{u}'_L(y_{\mathrm{Ref.}}, t+\delta\tau(y;y_{\mathrm{Ref.}})) E_L(\tilde{u}'_S(y,t)) \rangle_T}{\langle \tilde{u}'^2_L(y_{\mathrm{Ref.}}, t+\delta\tau(y;y_{\mathrm{Ref.}})) \rangle_T^{1/2} \langle E_L^2(\tilde{u}'_S(y,t)) \rangle_T^{1/2}}$

Large-scale component at fixed outer elevation and envelope of small scales at varying elevation



Thick lines: $R(y;y_{\mathrm{Ref.}})$; Thin lines: $R(y;y)$

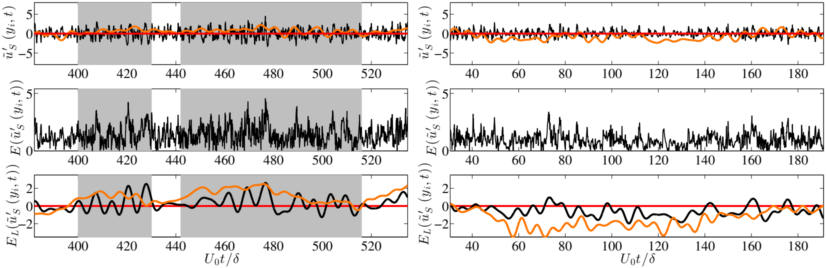
Note: $R(y;y) > R(y;y_{\mathrm{Ref.}})$

Blue lines: LES with $N_x = N_y = N_z = 96$; Black lines: $N_x = N_y = N_z = 128$

Black squares: smooth wall turbulent channel (Mathis et al., 2009: *Physics of Fluids*)

Anderson, 2016: *J. Fluid Mech.* **789** 567—588

Time series: cubic topography: Position x_4



Top figure: $\tilde{u}'_S(y_i,t)$ (black); $\tilde{u}'_L(y_i,t)$ (orange); $y_i/\delta = 0.254$

Middle figure: $E(\tilde{u}'_S(y_i,t))$ (black); $y_i/\delta = 0.254$

Bottom figure: $E_L(\tilde{u}'_S(y_i,t))$ (black); $\tilde{u}'_L(y_O, t - \delta\tau(y_O; y_i))$ (orange); $y_O/\delta = 0.5$

$$\frac{y_O}{y_i} \approx 2$$

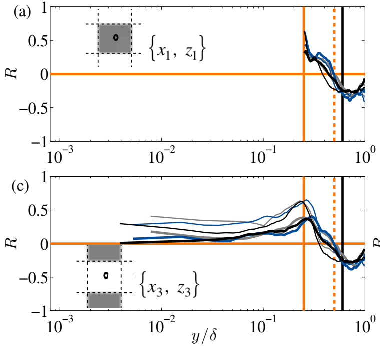
$\delta\tau(y; y_{\text{Ref.}})$ = advective correction

Now: correlate envelope of small scales with large-scale signal

Correlation: cubes

$$R(y;y) = \frac{\langle \tilde{u}'_L(y,t) E_L(\tilde{u}'_S(y,t))\rangle_T}{\langle \tilde{u}'^2_L(y,t)\rangle_T^{1/2} \langle E_L^2(\tilde{u}'_S(y,t))\rangle_T^{1/2}}$$

$$R(y;y_{\mathrm{Ref.}}) = \frac{\langle \tilde{u}'_L(y_{\mathrm{Ref.}}, t+\delta\tau(y;y_{\mathrm{Ref.}})) E_L(\tilde{u}'_S(y,t))\rangle_T}{\langle \tilde{u}'^2_L(y_{\mathrm{Ref.}}, t+\delta\tau(y;y_{\mathrm{Ref.}}))\rangle_T^{1/2} \langle E_L^2(\tilde{u}'_S(y,t))\rangle_T^{1/2}}$$



Thick lines: $R(y;y_{\mathrm{Ref.}})$; Thin lines: $R(y;y)$

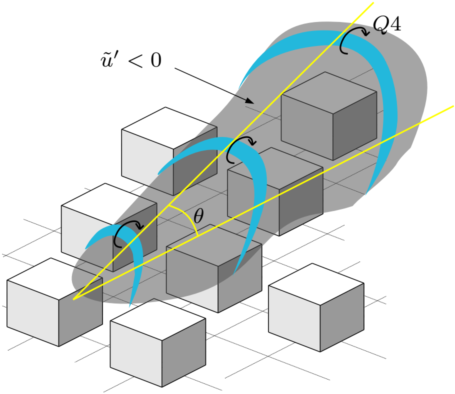
Note: $R(y;y) > R(y;y_{\mathrm{Ref.}})$

Gray lines: LES with $N = 64$; blue lines: $N = 96$; black lines: $N = 128$

Conclusion:

Under inertia-dominated ABL conditions

...Inertial layer amplitude modulates roughness sublayer



Mixing-layer-like roughness sublayer: positively correlated to inertial layer dynamics

But, location in canopy (secondary canopy flows) greatly influences correlation

AGU FALL MEETING
San Francisco | 12–16 December 2016

2016 AGU Fall Meeting sessions of interest to AMS BLT community:

Session ID 12480: A014 – Atmospheric Boundary Layer Processes and Turbulence (Atmospheric Sciences)
Primary Convener: David Richter; Co-Conveners: Chag Higgins, Will Anderson

Session ID 12334: EP004 – Aeolian Research at the Interface of Biophysical, Sedimentary, and Atmospheric Processes (Earth and Planetary Surface Processes)
Primary Convener: Will Anderson; Co-Conveners: Gianluca Blois, Kenzie Day, Jonathan Perkins

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- **Air Force Office of Scientific Research**, Turbulence and Transition Program
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- **Army Research Office**, Environmental Sciences Directorate
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- **The University of Texas at Dallas**
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